PHILOSOPHICAL

TRANSACTIONS

OF THE

ROYAL SOCIETY

OF

LONDON.

FOR THE YEAR MDCCCLXXXIII.

VOL. 174.—PART II.

LONDON:
PRINTED BY HARRISON AND SONS, ST. MARTIN'S LANE, W.C.,
Printers in Ordinary to Her Majesty.
MDCCCLXXXIII.

CONTENTS.

PART II.

IX. *On the Skeleton of the Marsipobranch Fishes.*—Part I. *The Myxinoids* (Myxine *and* Bdellostoma). *By* WILLIAM KITCHEN PARKER, *F.R.S.* . . . page 373

X. *On the Skeleton of the Marsipobranch Fishes.*—Part II. *Petromyzon. By* WILLIAM KITCHEN PARKER, *F.R.S.* 411

XI. *On the Organization of the Fossil Plants of the Coal-Measures.*—Part XII. *By* W. C. WILLIAMSON, *LL.D., F.R.S., Professor of Botany in the Victoria University, Manchester* 459

XII. *Experimental Researches on the Electric Discharge with the Chloride of Silver Battery.*—Part IV. *By* WARREN DE LA RUE, *M.A., D.C.L., Ph.D., F.R.S., and* HUGO W. MÜLLER, *Ph.D., F.R.S.* 477

XIII. *On Electrical Motions in a Spherical Conductor. By* HORACE LAMB, *M.A., formerly Fellow of Trinity College, Cambridge, Professor of Mathematics in the University of Adelaide. Communicated by* J. W. L. GLAISHER, *M.A., F.R.S.* 519

XIV. *Researches on the Foraminifera—Supplemental Memoir. On an Abyssal type of the Genus* Orbitolites;—*a Study in the Theory of Descent. By* WILLIAM B. CARPENTER, *C.B., M.D., LL.D., F.R.S.* 551

XV. *On the Affinities of* Thylacoleo. *By Professor* OWEN, *C.B., F.R.S., &c., Superintendent of the Natural History Department, British Museum* 575

XVI. *On the Morphology and the Development of the Perithecium of* Meliola, *a Genus of Tropical Epiphyllous Fungi. By* H. MARSHALL WARD, *B.A., Fellow of Owens College, Victoria University; late Cryptogamist to the Ceylon Government. Communicated by* W. T. THISELTON DYER, *C.M.G., M.A., Assistant Director, Royal Gardens, Kew* 583

XVII. *On the Atomic Weight of Glucinum (Beryllium). By* T. S. HUMPIDGE, *Ph.D., B.Sc. Communicated by Professor* E. FRANKLAND, *F.R.S.* 601

27799

XVIII. *On the Changes which take place in the Deviations of the Standard Compass in the Iron Armour-plated, Iron, and Composite-built Ships of the Royal Navy, on a considerable change of Magnetic Latitude. By Staff Commander* E. W. Creak, *R.N., of the Admiralty Compass Department. Communicated by Sir* Frederick J. O. Evans, *K.C.B., Hydrographer of the Admiralty* . . 615

XIX. *Pelvic Characters of* Thylacoleo carnifex. *By Professor* Owen, *C.B., F.R.S., &c.* 639

XX. *The Limiting Thickness of Liquid Films. By* A. W. Reinold, *M.A., Professor of Physics in the Royal Naval College, Greenwich, and* A. W. Rücker, *M.A., Professor of Physics in the Yorkshire College, Leeds. Communicated by* R. B. Clifton, *M.A., F.R.S., Professor of Experimental Philosophy in the University of Oxford* 645

XXI. *The Direct Influence of Gradual Variations of Temperature upon the Rate of Beat of the Dog's Heart. By* H. Newell Martin, *M.A., M.D., D.Sc.; Professor in the Johns Hopkins University, Baltimore, U.S.A. Communicated by Dr.* M. Foster, *Sec.R.S.* 663

Index to Part II. 689

LIST OF ILLUSTRATIONS.

Plates 8 to 17.—Mr. W. K. Parker on the Skeleton of the Marsipobranch Fishes.—Part I. The Myxinoids (*Myxine* and *Bdellostoma*).

Plates 8, 10, 14, 15, and 18 to 26.—Mr. W. K. Parker on the Skeleton of the Marsipobranch Fishes.—Part II. *Petromyzon.*

Plates 27 to 34.—Professor W. C. Williamson on the Organization of the Fossil Plants of the Coal-Measures.

Plates 35 and 36.—Messrs. W. De La Rue and H. W. Müller on the Electric Discharge with the Chloride of Silver Battery.

Plates 37 and 38.—Dr. W. B. Carpenter on *Orbitolites tenuissima.*

Plates 39 to 41.—Professor Owen on the Affinities of *Thylacoleo.*

Plates 42 to 44.—Mr. H. M. Ward on the Morphology and the Development of the Perithecium of *Meliola*, a Genus of Tropical Epiphyllous Fungi.

Plate 45.—Dr. T. S. Humpidge on the Atomic Weight of Glucinum (Beryllium).

Plate 46.—Professor Owen on the Pelvic Characters of *Thylacoleo carnifex.*

Plate 47.—Professors A. W. Reinold and A. W. Rücker on the Limiting Thickness of Liquid Films.

Plates 48 and 49.—Professor H. N. Martin on the Direct Influence of Gradual Variations of Temperature upon the Rate of Beat of the Dog's Heart.

IX. *On the Skeleton of the Marsipobranch Fishes.*—Part I. *The Myxinoids* (Myxine, *and* Bdellostoma).

By William Kitchen Parker, *F.R.S.*

Received December 14, 1882—Read January 11, 1883.

[Plates 8–17.]

Introduction.

At present, almost nothing is known of the development of these remarkable Fishes, but their structure in the adult state is of great interest; and as the other related type—the Lamprey—has received great attention lately in most of its stages, I have thought that it would be profitable to anatomists to have a detailed account of the structure of the skeleton in these lower, and less known types.

The late Professor Johann Müller left us his inestimable account of the anatomy of *Bdellostoma*, with excellent figures of the skeletal parts; but of *Myxine* he gave very few illustrations. Moreover, the absolutely accurate figures of the skull of *Bdellostoma* are small and uncoloured; they fail to show the various kinds of cartilage of which it is composed, and as this skull is so extremely unlike that of any other known vertebrate, except that of the Hag (*Myxine*), I venture to give my own (new) illustrations on a larger scale and coloured. My figures of the skeletal parts of *Myxine* will be, I believe, almost entirely new to science; and, moreover, the time seems to have arrived in which some *interpretation* of these low generalised skulls may be attempted.

This will be done by the help of what we have lately been learning of the development of the skeleton of the nearest relative of the Myxinoid—the Lamprey,—the subject of Part II. This attempt to explain the Myxinoid type of skull and skeleton generally—nearly all the cartilage in these fishes is *cephalic*—has been done by the help of our growing knowledge of the Lamprey, and also by comparison with what the writer has traced out in the early conditions of the skull in various types of Ichthyopsida, especially in the larva of *Lepidosteus*, and of a large number of Tadpoles of the *Amphibia Anura*.

The light thrown upon the Myxinoid cranio-facial apparatus by the early *chondrocranium* of other and much higher kinds of Ichthyopsida, is much greater than might have been expected, for these show, now here, now there, very remarkable archaic characters; and one kind, the Tadpole of the Nailed Toad of the Cape (*Dactylethra*), has these parts but little more specialised than in the Myxinoids; and, moreover, this type has all its cartilage (which is very copious and wild-growing), even in Tadpoles an inch long, of a peculiarly light and cellular kind—like many parts of the Myxinoid's skeleton. It is evidently *the historic representative* of an exceedingly ancient and generalised sort of Fish.

Most important help to me in this attempted interpretation has been repeated discussion of the subject with one of the very highest intellects ever devoted to Biological research—I allude to the late Professor BALFOUR; that source of light and strength is now, unhappily, lost to me.

Bibliography.

BALFOUR, F. M., F.R.S. 'Comparative Embryology,' vol. ii., 1881, pp. 68–83.

BERT. "Note sur quelques points de la Physiologie de la Lamproie." Annales des Sc. Naturelles. 5th série, tome vii. Zoologie, 1867, s. 391.

CALBERLA. 'Tageblatt der Muenchener Naturforscher Versammlung.' 1877.

FÜRBRINGER. "Untersuchungen zur vergleichenden Anatomie der Muskulatur des Kopfskeletes der Cyclostomen." Jenaische Zeitschrift für Naturwissenschaften, Bd. ix., 1875.

GEGENBAUR, C.

1. "Ueber die Entwickelung der Wirbelsäule von *Lepidosteus*." Jenaische Zeitschrift für Medicin und Naturwissenschaft, Bd. iii. (1867), S. 376.
2. "Ueber das Skelettgewebe der Cyclostomen." Jenaische Zeitschrift für Medicin und gesammte Naturwissenschaft, Bd. v. (1870), S. 43.
3. 'Untersuchungen zur vergleichenden Anatomie der Wirbelthiere.' (Drittes Heft: Das Kopfskelet der Selachier, ein Beitrag zur Erkentniss der Genese Kopfskeletes der Wirbelthiere). Leipzig: 1872.
4. 'Grundriss der vergleichenden Anatomie.' Leipzig: 1878. (Also English Translation by JEFFREY BELL, Esq., 'Elements of Comparative Anatomy.' London: 1878).

GÖTTE, ALEX. 'Entwickelungsgeschichte d. Unke.' Leipzig: 1875.

HUXLEY, T. H., F.R.S.

1. 'Elements of Comparative Anatomy.' 1864, pp. 189–194.
2. 'The Anatomy of Vertebrated Animals.' 1871, pp. 115–126.
3. "Preliminary Note on the Brain and Skull of *Amphioxus* and *Ammocœtes*." Proc. Roy. Soc., 1874, pp. 127–132.
4. "On the Nature of the Cranio-facial Apparatus of *Petromyzon*." Journ. of Anat. and Phys., vol. x., pp. 412–429; plates 17, 18.

KÖLLIKER, A.

1. "Entwicklung der Wirbel der Selachier." Verhandlungen der physikalisch-medicinischen Gesellschaft in Würzburg. Bd. x., 1860; Taf. 3, fig. 8.

2. "Kritische Bemerkungen zur Geschichte der Untersuchungen über Scheiden der Chorda dorsalis." Würzburger naturwissenschaftliche Zeitschrift, 1873, S. 7.

Mayer, Aug. Fr. J. C. 'Analecten für vergleichende Anatomie.' Theil I., 1835, S. 60.

Müller, Aug. "Ueber die Entwicklung der Neunaugen [*Petromyzon*]: ein vorläufiger Bericht." Müller's Archiv, 1856, S. 323.

Müller, J.

1. 'Vergleichende Anatomie der Myxinoiden, der Cyclostomen, mit durchbohrtem Gaumen.' Berlin: 1835.
2. 'Ueber den eigenthümlichen Bau des Gehörorgans bei den Cyclostomen.' Berlin; 1838.
3. 'Vergleichende Neurologie der Myxinoiden.' Berlin: 1840.
4. 'Vergleichende Anatomie der Myxinoiden.' Berlin: 1841.

Rathke, H.

1. 'Bemerkungen über den Bau der Pricke [*Petromyzon*].' Danzig: 1826.
2. "Bemerkungen über den innern Bau des Querders [*Ammocœtes*]: Beiträge zur Geschichte der Thierwelt." Abtheilung IV. Der Schriften der naturforschendenden Gesellschaft zu Danzig, Bd. xxi., Heft 2. Halle: 1827, S. 66.

Retzius, Gustav. 'Das Gehörorgan der Wirbelthiere,' vol. i. Stockholm: 1881.

Schneider, Anton. 'Beiträge zur vergleichenden Anatomie und Entwickelungsgeschichte der Wirbelthiere.' Berlin: 1879.

Schultze, M. S. 'Die Entwickelungsgeschichte von *Petromyzon Planeri*.' Haarlem: 1856.

Scott, W. B. (Princeton, New Jersey, U.S.) 'Preliminary Account of Development of Lampreys,' &c. Princeton: Nov. 29th, 1880.

Wiedersheim, R. 'Morphologische Studien.' Heft I.: "Das Gehirn von *Ammocœtes* und *Petromyzon Planeri*, mit besonderer Berücksichtigung der Spinalartigen Hirnnerven." Jena: 1880.

On the Varieties of the Connective-tissue Series found in the Skeleton of the Myxinoids.

There are four kinds of supporting-tissue in these types, namely:—

a. A very solid greenish kind of cartilage, seen in these Fishes and the Lamprey, only, as far as my experience goes; it is formed by special deposits in the softer kind.

b. Soft cartilage; colourless, and with but little inter-cellular deposit; passes insensibly in some places, suddenly in others, into hard cartilage.

c. An elastic, spongy tissue, full of large vacuoli, a degree denser than the tissue of the notochord.

d. White fibrous tissue, often exceedingly compact and strong; it may, for the present, be called *fibro-cartilage*.

On the relation of the Myxinoids to other types: their Zoological position in the "Branchiata," or "Anamniota."

Roughly, this may be expressed as follows: The Hag and *Bdellostoma* are a sort of greatly modified *Ammocœte;* they bear a relation to the Lamprey similar to that which it bears to the Anurous Amphibia. The *secular losses* among these types must have been very great indeed, for although the Marsipobranchs and the Anura—which are Marsipobranchs in their larval state—are akin to each other to a degree in which they are not akin to any other Branchiata, yet they are very far apart from each other, after all. The metamorphosis of the Tadpole lifts it far above the highest of the Marsipobranchii proper, but I feel satisfied that the Anura have only gradually become metamorphosed; and I doubt whether *all the larvæ of Pseudis* undergo that change, even now. Yet when once this change is set up, we see a very generalised and archaic Fish become *almost* a true Reptile. More than this, one kind—*Pipa*—scarcely shows a trace of gills, and all the Anura, during their metamorphosis, develop a "bladder" which is, *apparently*, the rudiment of an "Allantois;" if further research makes this supposition a settled fact, the stride made by these forms, during individual life, will be seen to be very great indeed.

It is better to call the Hag and Lamprey "Marsipobranchs" than *suctorial fishes;* the adult Lamprey, like the Tadpole, is truly suctorial, but the mouth of the *Ammocœte* or larval Lamprey, and the mouth of the Hag and *Bdellostoma*, are not modified into a circular sucking ring, but it remains as a small hooded opening, fringed with short barbels, or oral palpi. There is no cartilage whatever in the mouth of the *Ammocœte* (Plate 19, figs. 4, 5), and in the Myxinoids the only cartilage developed is as a pith to the barbels (Plate 17, figs. 1–3). All this will be explained in the sequel, but we may as well start fairly, looking upon the subjects of the present paper as greatly specialised, but not metamorphised, "Marsipobranchs," a curious variety of arrested "Sand Pride," or *Ammocœte*. In my Second Part I shall show how such a simple type is transformed into a true Sucking Fish, or Lamprey, which may be, in turn, looked upon as a sort of highly specialised, but arrested, Anurous Amphibian.

On the cranio-facial apparatus of the adult Hag-Fish (Myxine glutinosa).

All the cartilage to be found in this Fish is *cephalic*, for even the furthest rudiment of the dorsal part of the branchial basket is, like the rest of that system, supplied by a cranial nerve—the vagus; the spinal region is only supported by membrane, or strong, fibrous tissue.

Properly speaking, these Fishes, although *Craniata*, are not *Vertebrata;* they are *chordato-craniata* like the Lamprey before its metamorphosis, for neither in this, or in the large Cape species (*Bdellostoma*), can I find any cartilaginous rudiments of vertebral arches. Moreover, the *theca vertebralis* is but little enlarged where it passes, insensibly, into the *dura mater*.

The huge notochord (Plates 9 and 10, figs. 1, 2, *nc.*), with its *merely membranous* sheath, suddenly ends in a conical form between the ear capsules, its thick sheath becoming still thicker at the end, and the vacuoles and membranous bands ceasing very close to the hind part of the head, which is not definitely separate from the spinal region.

Hence the parachordal region, or investing mass (*iv.*) is very short, only one-fifth the length of the entire skull; its moieties become the trabeculæ (*tr.*) at the front third of the auditory capsules (*au.*) The right and left bands unite below (Plate 10, fig. 3) but not above (figs. 1, 2); there they do project a little behind the capsules, but, below, this is hardly perceptible. Thus, the basi-occipital cartilage is incomplete. Moreover, it is arrested behind, for there are not only no condyles, but the cartilage stops in front of the place where they would be found. The sides, or ex-occipital region, and the roof or super-occipital, are arrested, entirely; thus there is no occipital ring. At this hind part the *theca cranialis*, or "dura mater" lies on an imperfect floor of cartilage, but for the rest of its extent the trabeculæ lie rather outside than under it, and only meet and unite under the nasal capsule (*na.*) Thus the huge oval "fontanelle" reaches from end to end, and is only separated from the inferior or pituitary fontanelle by the thick lateral (trabecular) bands; yet a secondary cartilaginous part forms a partial floor to the *pro*-chordal part of the skull. The fore part of the skull has a peculiar ox-faced form, ending in two crescentic "horns;" behind these horns it narrows gently, and then widens out in an even, rounded manner, the widening being due to the facial basket-work.

The whole structure is, indeed, a generalised cranio-facial basket-work. There is no proper segmentation, but here and there the cartilage remains soft, and thus certain of the territories are marked out.

That which is so puzzling in this little unossified skull is its primitiveness and simplicity; for we are accustomed to cranial and facial structures that are differentiated from each other, and in which the facial arches are segmented into a number of parts; these can be classified and named, a typical arch being made the measure of the rest.

Here we have unenclosed land, and in such a generalised, common field, any balk, mound, stone, or bush may be useful as a landmark.*

The "horns" are not the *cornua trabeculæ;* these are suppressed in *Myxine*, but they belong to the palatine *region*, and so does at least half of the fore part of the cartilage bounding the narrow cranial cavity. The two trabeculæ are confluent in front, between the "prepalatine" horns (*pr.pa.*), and where they unite in front there is a wedge of soft cartilage; also the inner edge of the basal cartilage (*iv.*) behind, under the hind-brain, is soft. As to the lateral bars, the eye seizes upon a landmark; this is the "subocular fenestra" (*s.o.f.*), very familiar to us in the skulls of Tadpoles. Inside this very limited reniform membranous space the bar is purely trabecular. In front of it it is palato-trabecular (*pa.*, *tr.*). Another familiar part can now be seen; it is behind the fenestra, and is composed of soft cartilage; this short tract is the pedicle (*pd.*), for it answers to the dorsal end of the great "suspensorium" or palato-quadrate of the Tadpole, a part always developed continuously with the basis cranii in the Anura. (See "Batrachian Skull," Part II., Phil. Trans., 1876, Plate 35, figs. 1–5, *pd.*). An oblique soft tract may be seen in front of the subocular fenestra in *Myxine;* this marks the junction of the pterygo-quadrate region with the palatine. The prepalatine horns (*pr.pa.*) remain soft; they are large, rounded, and suddenly apiculated near their end. Now, for a while, the Tadpole's skull will fail us in our interpretation; as long as I kept, slavishly, to that chondrocranium, as my key to the skull of the Marsipobranchs, I was always falling into confusion. The Tadpole's skull, however, just when transformation is taking place, and the skull of the *suctorial larva of Lepidosteus*, greatly enlighten us at this point. (See "Skull of Batrachia," Part III., Plate 4, figs. 5–9, and "Skull of *Lepidosteus*," Phil. Trans., 1882, Plate 30, figs. 3, 7, 8.) Here we have to be cautious; for *Myxine* has its *quadrate region* suppressed at the part where the condyle is formed in the higher kinds, and there are no Meckelian or mandibular rods. Hence that huge, broad, condyle-bearing part of the enormous suspensorium of the Tadpole shown in so many of my figures, and often running up to the front of the face, is not present in *Myxine*. Moreover, I am quite persuaded that the rudiment of the quadrate region (*q.*) which does exist, is not in front, but directly below the pedicle (*pd.*), a position which is only slowly gained in the Tadpole; in *Lepidosteus* it is not far in front of the pedicle, being opposite the pituitary body ("Skull of *Lepidosteus*," Plate 30, fig. 3, *py.*, *q.c.*).

---

* If the reader would follow the description and interpretation here attempted, it would be well for him to have the other papers of the writer before him, especially the following, namely:—"Skull of Batrachia," Part II., Phil. Trans., 1876, Plates 54–62; "Skull of Batrachia," Part III., Phil. Trans., 1881, Part I., Plates 1–44; and "Skull of *Lepidosteus*," Phil. Trans., 1882, Plates 30–38. The nomenclature shall be as uniform as I can make it.

The remarkable position of the distal part of the "pier" (or suspensorium) of the mandible in the Tadpole is quite unique; it exists nowhere else but in the Anura, and depends upon the compromise, so to speak, which in them is made between a jaw-less and a jaw-bearing type. I must return to the arrested jaw-pier and its connexions with the rest of the facial basket-work, when the rest of the cranium has been described.

In the Tadpole the trabeculæ, after a time, become united together beneath the fore brain by a thin lamina of cartilage, the soft tissue gradually becoming cartilaginous; but this posterior intertrabecular tract is not found as a distinct sheet of cartilage. Afterwards, when the trabeculæ of the Tadpole have united in the ethmoidal region, a crest of cartilage appears upon it, which becomes the vertical ethmoid and septum nasi in one high tract ("Batrachia," Part III., Plate 2, fig. 1). In the Green Turtle, I have shown that the intertrabecular cartilage is found as a rounded rod between the rounded paired trabeculæ, and that afterwards they flatten out, and it rises upwards to form the ethmo-septal partition of the nasal region ('Challenger Memoirs,' vol. i., part 5, plate 2, figs. 3–7).

This is the manner of growth seen in all Reptiles above Serpents, in Birds, and in Mammals. Here, in the lowest kind of skull we know of, the median prochordal cartilage appears as two tracts, one before the other, the two quite independent of each other, and very much unlike in form and consistency; so that the skull itself in the Myxinoid is formed of separate segments, although the facial arches are not differentiated (or segmented) from the edges of the paired cranial bars.

The long oval space in front of the short parachordal tracts, reaching from there to the ethmoidal commissure (Plate 10, figs. 1, 2, 3), is imperfectly closed below by a remarkable spoon-shaped cartilage of the soft kind; this is the *hinder intertrabecula* (*p.i.tr.*). Under the proper pituitary region, we see the bowl of the "spoon," which is rostrate and perforate behind; the straight, narrow "handle" runs forwards, touching the ethmoidal commissure: it gently lessens from behind, forwards. The handle leaves a large unfloored space right and left; it is gently scooped above, and the "bowl" considerably; this lamina is of even thickness, and is quite convex below. At some height above the end of the handle, a new cartilage begins, very different from the last; this is the *front intertrabecula* (*a.i.tr.*). This bar is composed of hard cartilage; it is compressed vertically, is as wide as the handle of the "spoon," but higher than wide; it is thickest behind, where it is emarginate and acutely bilobed; and it narrows gently forwards, and is then thickened again. This "front intertrabecula" is one-sixth longer than the other, and more than its hinder fourth lies *on* the ethmoidal commissure, and *under* the long nasal labyrinth (*n.a.*, *e.n.t.*). These structures are quite unlike what is seen in the Lamprey, where the cornua trabeculæ are connate, and abort the front intertrabecula, and where the hind intertrabecula is composed of hard cartilage, and is only distinct for a very short time after metamorphosis (Plate 10, figs. 4, 5, *p.i.tr.*). The state of things seen in *Myxine* is evidently due to the *intense* specialisation of a type, which, on the whole, does not rise above the level (or *platform*) of an *Ammocæte*. Some other "novelties," quite equal to this, will be seen as we proceed.

Below the middle of the auditory capsule (Plate 9, fig. 2, *au.*), there is a round fenestra (*m.h.f.*), half as large as the reniform subocular space (*s.o.f.*); and below this, separated by a thick bar, is another oval space (*l.f*^{2}.), twice as large as the subocular. These, also, are nascent segmentation lines, arrested and widened out. The bar bounding the little upper space, behind (*h.m.*), is quite similar to, but wider than, the one in front—the pedicle (*pd.*); it is also composed of soft cartilage, whilst the thick bar running backwards from the pterygoid region under the reniform, and round and over the oval, fenestra, is hard cartilage. The narrow end of the oval fenestra looks upwards and forwards, and the hard bar below and in front of it, which lessens, and then widens out again, is the pterygo-quadrate bar, ending below, not in a *quadrate condyle*, but in a thin, inturned edge, somewhat rounded in outline. The hard cartilage ends, above and below, a little behind the large oval fenestra, and at its hind margin, and in the rest of the basket-work, the cartilage is soft. Like the pedicle, the short bar (*h.m.*) behind the small, round fenestra is continuous with the parachordal (*iv.*); it is the "serial homologue" of the pedicle of the suspensorium, and therefore is the head of the hyoid arch (= head of the hyomandibular). Now we begin to feel our way in this *unenclosed field*; we have lit upon some landmarks. One continuous growth of cartilage is seen running sinuously, sub-parallel with the axis, from near the fore-end of the nasal tube (*e.n.t.*) to a point beneath the 3rd spinal nerve (*sp.n.*). The fore part is what I have called the prepalatine "horn," or spike (*pr.pa.*); it is soft; then the hard tract behind it is first palatine (*pa.*), and then becomes the top of the pterygo-quadrate region (*pg.*, *q.*), passing into the "shoulder" of the hyomandibular (*h.m.*), the fore part of which answers to the wide snaggy part of that bone in an Osseous Fish, whilst the hind part corresponds to its "opercular process" for the *os operculare.* The hard cartilage of the pterygoid region is separated from that of the palatine in front, and the quadrate behind and below, by a narrow soft tract. The soft cartilage behind is first inter-hyal (*i.hy.*) then epi-hyal (*e.hy.*), and then forms the top of the 1st epibranchial ($e.br^1$.) The margining cartilage behind the large oval fenestra, sends back a rounded lobe into the hinder fenestra ($l.f^3$.)—a two-horned space; that lobate band is the "symplectic" region (*sy.*); it is soft; but the back of the quadrate region, into which it passes, is hard. The largest or hindmost two-horned fenestra although single below, is broken into two, above, by the main part of the hyoid arch—the inter-, epi-, cerato-, and hypo-hyal regions (*i.hy.*, *e.hy.*, *c.hy.*, *h.hy.*).

This arched band, bending backwards, and growing downwards and forwards, to pass into the huge basal bar, is both wider and thicker than that of an adult Frog, but unlike its counterpart in that type it is continuous with the upper or hyomandibular part of the arch. Nevertheless, its small width here suggests comparison with the hyoid of the adult, and not of the larval Frog, whose broad, short lower hyoid is suspended from the suspensorium, beneath the eye-ball, indeed under the front of the subocular space. Here the hyoid arch is curved backwards so as to lie, in the middle, below the 1st spinal nerve (*sp.n.*) whilst the arrested quadrate tract (*q.*) is directly below the middle of the auditory capsule, a position attained by the quadrate condyle of the Frog soon after metamorphosis. Where the soft cartilage of the hypo-hyal region (*h.hy.*) ends below, there the hard cartilage of the basi-hyal ($b.hy^2$.) begins, but there is no joint.

This continuous hyoid bar, as we have seen, passes over the last, or two-horned fenestra dividing it, above, and then riding over it. Above, this hyoid bar passes directly into the arched cartilage bounding the hind fenestra; below, that boundary of cartilage passes inside the long hyoid bar, and becomes the symplectic region. From its convex margin, behind, this hinder arch gives off two styliform outgrowths. This semicircle of soft cartilage, which forms the hinder half of the boundary of the hinder fenestra, is the 1st epi-branchial; the 1st cerato-branchial is suppressed in *Myxine*, but well-developed and distinct in *Bdellostoma* (Plate 16, figs. 1, 2, *c.br.*).

But the 1st pharyngo-branchial, or pier of the 3rd visceral arch, is well developed in both kinds; here (Plate 10, figs. 1–3; and Plate 17, figs. 1–3, *p.br*^{1}.) it is free from its own proper descending bar, lies obliquely inside it, and is joined to the general thickening of cartilage in the hind part of the *oval* fenestra. Thence it is very thick, and clavato-lobate, filling up nearly half of the fenestra at its inner face; it is there composed of hard cartilage. The rest is a soft, long, sinuous, inbent rod, which ends in a point some distance behind the *epi-branchial rays* (*e.br*^{1}.). Of the 2nd branchial arch only the upper or pharyngeal part is developed; but the relations of this and of the 1st pharyngo-branchial, enable us to determine the nature of these cartilages as to whether they are *extra*-branchials or *intra*-branchials. When the lower part of the throat of *Myxine* is removed, and the pharynx slit open for some distance (Plate 13, fig. 7), then we see that behind the pharyngeal opening of the posterior nasal canal (*p.n.c.*) there is a peculiar hood of membrane, the "pharyngeal velum" (*vl.*); it is pyriform, its narrow end is crenate, and a septum divides it behind, between the terminal folds.

When this is dissected out and examined from below (Plate 15, fig. 6), then we find that the 1st pharyngo-branchials are the supports of its outer margin, and that its swelling part has a skeleton derived from the 2nd pharyngo-branchials. The branchial pouches and clefts, *during growth, retired far away from the skeletal framework* (Plate 9, fig. 1), so that the cleft or opening of the first or *hyo-branchial* pouch lies below the *twentieth spinal nerve* (*sp.n.*); and the middle of the pericardium is below the *fortieth* (*sp.n.*). All these retired parts, pushed back, *so to speak*, by the huge lingual apparatus, are supplied by a cranial nerve, the vagus—a remarkable "prophecy" of what will take place in the retirement of the respiratory organs in the higher Vertebrata. The framework of the branchial region is left in its place, and is largely suppressed, and the parts that are developed are free to form new specialisations. The lower part of the pharyngeal velum, covered by *hypoblastic* cells, is supported by the 2nd pharyngo-branchials (Plate 15, fig. 6, *p.br*^{2}.), which are a pair of nbent, obliquely placed rods, thickish in front and very slender behind. At their middle they are united by a transverse bar, and this bar sends forwards two slender rods, which grow in front into large, pedate lobes. Where the slender hind part turns outwards, in the crenations of the velum, there another transverse rod is formed, thus uniting the right and left bars together; this also sends off, backwards, a small median outgrowth, and two large, lateral, multilobate outgrowths—a curious moss-like structure.

On the *right* side the rays of the 1st epi-branchial (Plate 10, figs. 1, 2, *e.br*^{1}.) are united at their base, and form another fenestra, so that there are *four* visceral fenestræ on the left side, and *five* on the right.

And yet this remarkable basket-work is not homologous with the curiously similar growth in the Lamprey; in that Fish the reticulation is formed outside the head-cavities; in the Hag-Fish they *must have been formed within* them, as they lie close to the hypo blastic lining of the throat.

With regard to the great inferior median bar (*b.hy.*, *b.br.*), there can be but little difficulty; for not only the Lamprey, but the Bony Gar-pike (*Lepidosteus*) also, shows us a similar huge glosso-hyal in front of the common basi-branchial bar. In the latter Fish (Phil. Trans., 1882, Plates 30–38) the basi-hyal is double, composed of two equal rounded rods, which are united along the middle. Moreover (most instructive of all the characters of that remarkable lingual skeleton), the cartilage is cut up into a number of transverse blocks by fibrous septa. This takes place in a Ganoid Fish, whose larva has a suctorial snout.

In the Myxinoids the tongue dominates the whole body; everything else yields to it, and is modified intensely by it. In the Lamprey, as well as in *Lepidosteus*, the basi-hyal becomes double in front, here it is a four-fold bar or plate; the solid cartilage being divided as it goes on expanding from behind forwards, first into two and then into four pieces (Plate 9, fig. 3); these are at once united and separated by tracts of soft cartilage or fibro-cartilage, and even by mere fibrous tissue in some places; and the two inner pieces of the terminal front part have a fenestra between them, behind. Then the bar becomes sub-carinate, but this angular projection is gradually lost, and the cartilage suddenly becomes soft, and a mere thick, *almost* fibrous web, is continued backwards behind the hypo-hyal junctions as an *anterior* basi-branchial ($b.br^1.$), which is one-third longer than the basi-hyal region.

Near the middle, this soft *fibro-cartilaginous* bar becomes keeled and alate; it then lessens gradually to a sharp point, which is gently upturned; this hinder part of the huge median bar is scooped on its upper surface; but the scooping becomes deeper and deeper, as we pass forwards to where the great fourfold basi-hyal is carinate below. The two middle pieces, in front, together form an emargination, and the outer pieces are rounded off externally. In front, the great lingual bar is twice as wide as the alate part of the basi-branchial behind. This huge beam is swung from the head, in front of its middle, by those small, soft ropes, the descending hyoid bands (*c.hy.*), which broaden and harden into the hyomandibular region (*h.m.*), above. The broad, emarginate fore-end of the huge lingual cartilage nearly reaches to the tips of the lower barbels, two pairs of which are seen protecting the slit-like mouth; whilst seven more protect the opening of the *nasal proboscis* (Plate 13, fig. 7).

The supra-lingual apparatus of Myxine.

The great basal bar (Plate 9, figs. 1–3, *b.hy.*) is only the coarser part, so to speak, of the lingual dentary apparatus; the two rows of teeth, right and left, themselves are set in a cushion of fibrous tissue, which is supported by a *supra-lingual* cartilage (Plate 12, figs. 7, 8), a *superadded* structure, the rudiment of which only re-appears in the Lamprey with one row of teeth right and left (Plate 14, fig. 9); in both cases these are peculiar to the Marsipobranchs.

When the great lingual cartilage, with the parts carried by it, is dissected out we have the structure shown in Plate 12, fig. 7; and when the teeth are removed, then the "supra-lingual" framework is seen (fig. 8), a curious *apron* with slits in it, and short strings projecting from it; it is composed of hard and soft cartilage, and of fibrous tissue ending, in front, in a horny comb; the figure shows it as considerably outspread, for display;—the sections correct this. In this hollow space lie the lingual teeth (fig. 7, *s.l.t.*); the cartilage had better be described first. This additional skeletal structure is formed in the floor and sides of the oral mucous membrane, and, with the structures it carries, reduces the cavity to a number of narrow chinks. The general outline of the supra-lingual frame-work is heart-shaped, but widely open, with projecting spurs, behind, whilst in front it is transverse, slightly emarginate, and developed into a fine comb of horny spikes. The fore part is membranous, but the cartilage creeps into this membrane, right, left, and in the middle—most there; there the fore margin of the cartilage has a small, toothed emargination in the middle and a large transverse notch, right and left. The whole cartilage tends to break up into a series of three pairs of short arches; within the hinder half there is a median bar between; these, together, form a sort of *intra-visceral* series, mimetic of the proper visceral arches, just as the *extra-visceral* framework of the Lamprey's pharynx is mimetic of such a series.

The first pair of these semi-segmented arches is wing-like, and is half separated by the next pair, which are narrow and feeble; one snag ends both of these behind; a crescentic cleft divides these for three-fourths of their extent; these two first pairs are composed of soft cartilage. The hinder pair ends in a snag, which is soft, and which is continuous in front with the root of the first snag. The side bars are twice as large as those in front of them, and are composed of hard cartilage; the median bar is soft, projects a little into the notch in front of it, and much more behind, where it reaches nearly as far backwards as the second pair of lateral processes. As it lies on the large basal beam, this hinder median part reaches as far back as the hard cartilage, and further than the setting on of the hypo-hyal ends of the hyoid arches (*h.hy.*).

In front, the horny comb helps to fill in the emargination of the basal beam.* The arrangement of the golden-coloured horny supra-lingual teeth is in a double, arched series, with a large notch behind. There are *seven* large teeth and *nine* small ones on each side; the large teeth are in front of, and outside, the others; their points look backwards, and inwards, and they are shaped like a lancet blade, but with a slight curve, the convexity being antero-internal. A cavity can be seen in them, and also that they are made of fibres arranged featherwise. The thick horny layer is continuous at the base of the teeth; their form is due to the folding of the lining membrane of the mouth, which undergoes *corneous hypertrophy* of the cells. These structures will be described again, when we come to the *sections*. The only *antagonist* tooth is very large and canine-shaped, attached to the ethmoid below, and pointing backwards (Plate 10, fig. 3, *et.t.*); an arrangement similar to that in "Cyprynoids," where the basi-occipital, horny tooth antagonises the lower pharyngeal, true teeth.

---

* There may seem to be some discrepancy between the figures of the huge basal beam—upper, lower, and lateral, and of the *sections* that illustrate its structure still further. The explanation is this: the *dissections* show the bars as invested with a strong perichondrium, and thus they *look* nearer together than they really are. The colouring of the dissections takes no account of this: the numerous sections, drawn with a *camera*, show the width of the intercartilaginous spaces.

On the branchial pouches of Myxine.

The extraordinary displacement of the branchial pouches in the Myxinoids is correlated with, or even caused by the enormous size of the lingual apparatus, the fore part of the great common basi-branchial bar being retained with the basi-hyal at the hind part of the lingual skeleton (Plate 9, figs. 1–3). But even this only reaches half way along the base of the oblique muscles that work the tongue. There is, however, a second basi-branchial bar (fig. 4, $b.br^{2}$.), slenderer and flatter by far, and only half the length of the main part; this is composed of hard cartilage, and after a space equal to its own length finishes the skeleton of the apparatus along the basal line.

In *Myxine* there is no skeleton to the *six pairs*[*] of cake-shaped (*placentiform*) branchial pouches, but the whole structure is membranous (see J. MÜLLER, I., plate 7, figs. 10–12; and my figure Plate 9, fig. 1).

Each pouch opens inwards into the narrow pharynx by a wide passage, and outwards by a largish tube which communicates with the opening of each succeeding tube, until they all have a common escape opening, behind. Into this space, on the *left* side, there is a sort of *fistulous passage*—the "ductus œsophago-cutaneus" (*d.œ.c.*) behind the last pouch—a sort of abortive gill-cleft, with no gill structure, the use of which I cannot see, but the morphology of which is self-evident. Behind these is the large heart (*h.*), giving off the arterial arches to the gill pouches.[†]

On the sense-capsules of Myxine.

For a detailed account of these organs, the reader is referred to MÜLLER's Memoirs; and for the auditory organs, especially, to Professor RETZIUS's magnificent volume, just published.[‡]

---

[*] Mr. WELDON informs me that he has found some specimens of *Myxine glutinosa* with *seven* pairs of pouches.

[†] For details see J. MÜLLER, I., plate 7.

[‡] 'Das Gehörorgan der Wirbelthiere,' vol. i., plates 1, 2, pp. 3–12. Stockholm: 1881.

To *me* they are part of the skeleton, and therefore come into my description. The eye-balls are extremely small, and inconspicuous (Plate 13, fig. 1, *e.*, II.). The auditory capsules are very small, but not so small by far as the eye-balls; they are kidney-shaped, and look much larger below than above (Plate 10, figs. 1–3, *au.*). Indeed, below they are oval in form, with the narrow end in front, and, above, the concavity of the inner face, which is largely membranous, gives them their reniform appearance; they are composed of hard cartilage, and look like little light green seeds. They are confluent with the basis cranii and head of the hyomandibular cartilage; I shall show this in my account of the *sections*.

The nasal capsule of the Myxinoids is a unique structure; it is composed of the true olfactory organ and the vestibular region, which is proboscidiform (Plates 9, 10).

The proper olfactory organ is covered with a *grating* of cartilage (*na.*), whose bars run in a longitudinal direction.

The whole capsule is wider than long—wider than the brain cavity—is gently emarginate behind, and apiculate in front. The floor is membranous, and lies over the brain cavity behind, and the "front intertrabecula" in front. The roof and sides are enclosed by the cartilaginous grating, in which there are *nine* sub-equal bars, united fore and aft by a continuous belt of cartilage; the bars and these interspaces are nearly equal. The olfactory nerves enter the *membranous cribriform plate* by five distinct bundles (see in *Bdellostoma*, Plate 17, fig. 4—an anticipation of the Mammalian ethmoid).

The proboscidiform nasal tube is very exactly like a *Mammalian trachea*, being composed of a series of imperfect cartilaginous rings, of which I find *eleven* in *Myxine*, the last being apiculated; it projects forwards above the single narial opening; these parts will be better understood when we come to the *sections*. The upper seven *barbels* or "nasal palpi" protect this opening, and the other four the oral opening; they each have a delicate cartilaginous axis. This type of skull remained an utter enigma to me until lately, even with the great work of MÜLLER before me; and I am not aware that any one, except Professor HUXLEY, has, of late years, attempted to interpret it; nor should I have attempted now, if the task had not been lightened by my fellow workers, and if the early stages of the nearest relatives—the Lamprey, and the "Anura" in their larval stages—had not been mastered.

Of course, every determination of the nature of parts made now will be subjected to a severe and crucial test when the early stages of a true Myxinoid have been worked out. For those stages I am anxiously looking; but, meantime, this initial work will be something done; a little change of nomenclature, if needed afterwards, will be no great matter; and it is very important that this *scarcely vertebrate* type—it has no *vertebræ*—should be understood. The number of sections drawn is great, but they were all needed to make even *the worker himself* understand what lay before his eyes. The reader will need to keep the figures of the dissections (Plate 9, figs. 1–3, and Plate 10, figs. 1–3; Plate 12, figs. 7, 8; and Plate 15, fig. 6) before him whilst reading the following description of the sections; the figures of the undissected Fish (Plate 8, figs. 7–9) will also be found useful.

Vertically transverse sections of the adult Myxine glutinosa.

Before describing these sections, I may remark that the nasal passage carries the upper lip far in front of the lower; but the lower lip, even in the *Ammocœte*, is far back; whereas, in the adult Lamprey, the lower lip, *when the sucking disc is in action*, projects beyond the "anterior dorsal cartilage," and its enclosing skin, the upper lip.

The end of the external nasal passage is protected by nasal barbels, and the mouth opens further back; there are two pairs of oral barbels, the outer unciform and the inner mammillate. There are three nasal barbels on one side and four on the other; *six* thin sections of this part, one of which was drawn, show this; and, corroborative of this fact, Dr. GÜNTHER, in his 'Study of Fishes' (p. 695, fig. 320, A) gives, in a woodcut, the same number in *Myxine Australis*.

Section 1 (Plate 11, fig. 1).—Here the interior valvular opening of the external nasal duct (*e.n.*) shows four points of cartilage (*n.bb.*) cut through on one side, and three on the other; the lesser barbels are close to the passage, and the larger further out; the fore end of the prepalatine reaches to this point.*

Section 2 (fig. 2).—The nasal canal or passage (*n.p.*) is now complete, and the first ring is cut through in three places, above, and on each side (see also Plate 10, fig. 1); for this imperfect *annulus* has a rostrum. Right and left of the vertically elliptical passage, the largest nasal palpi (*n.bb.*) and the prepalatines are cut across. The median line, below, is concave; this hollow leads to the oral passage further back. The upper outline of this section shows two sub-marginal shallow grooves

Section 3 (fig. 3).—In this the sub-marginal grooves above are nearly obsolete, and the middle part of the top is slightly crested; it is slightly grooved in its broad, lower part. The prepalatine cartilages (*pr.pa.*) are now flatter and wider apart; the section is through their arch in the middle. This shows a wider but lower passage (*n.p.*), widest below, and it is also seen that the annulus just reaches the bottom, and is thickened there. Under the nasal passage, the dilated fore end of the front intertrabecula (*a.i.tr.*) is cut across; the bend downwards of its edges makes it like a *Chinese bridge*.

Section 4 (fig. 4).—Here, in this larger section, both the upper and lower surfaces are hollow in the middle; the nasal canal is becoming pyriform, with the narrow end below. The annulus is like that of the last section, but larger; but the prepalatine and front intertrabecula (*pr.pa.*, *a.i.tr.*) are both flat in section; here the prepalatine has evidently been cut through very obliquely. The hard front intertrabecular bar is club-shaped in section in this and the next, the thick part being above.

---

* The lower, larger sections of cartilage are, by mistake in this and the next figure, lettered, with the rest, as nasal barbels (*n.bb.*); they are the free ends of the prepalatine spurs.

Section 5 (fig. 5).—Here the pre-oral groove is deeper, and the front intertrabecula is here at its largest part. The true form of the prepalatine section (*pr.pa.*) is seen here. In this section, and in the 7th and 8th, we get a view of an important character in the nasal passage (*n.p.*), namely, that it has a valvular fold in it, growing down from above, and making it heart-shaped in section.

Section 6 (fig. 6).—This section is much larger than the last, and here we have the upper lip breaking into two large, sharp folds,* and the palatal part of the oral vestibule wrought into two rounded folds. The valvular process of the nasal passage was not clear in this section, but we see that here the *annulus* is not thickened below, and that it turns inwards right and left. The front intertrabecula (*a.i.tr.*) is now long-oval in section, and the prepalatine (*pr.pa.*) oval. In the two folds of the upper lip (*u.l.*) we have the oral palpi (*o.bb.*) cut through, the outer longitudinally, and the inner across.

Section 7 (fig. 7).—In this section the two lobes of the upper lip (*u.l.*) are confluent, but the palpi (*o.bb.*) still come into section in a similar manner to the last; there are now five folds of the prepalatal region above, and two below; these latter look upwards, the meaning of which will soon be seen (see figs. 8–11). The valvular fold in the roof of the nasal passage is here clearly shown, and also the lessened depth of the front intertrabecula (*a.i.tr.*). The true thickness of the prepalatines (*pr.pa.*) is here shown, just at their base; and here also (see Plate 10, figs. 1–3) the ethmoidal region of the skull (*eth.*), with its attached conical yellow tooth (*et.t.*), is cut across.* The closed-in, or ethmoidal part of the skull is formed, as we saw, by the coalescence (or continuity) of the palatine bars outside, and the trabeculæ within; here, at the junction of these parts, the cartilage is high above, and gently convex below, where it carries the tooth.

Section 8 (fig. 8).—The section through the dilated hind part of the front intertrabecula (see Plate 10, fig. 2, *a.i.tr.*) was not figured; here, in front of that part, it is nearly circular in section; and because of the sinuous form of the hinder *narial annuli*, this section shows one cut into three pieces (*e.n.t.*); the nasal tube still shows its valvular character up to the proper capsule. The ethmoidal region (*eth.*) is arched; the outer part is palatine, and the middle trabecular. A cushion of fibrous tissue fills the concavity, and to it is attached the great tooth (*et.t.*), which is here cut across obliquely near its apex, showing its internal cavity. The lining of the mouth is sinuous, and the floor of it is now complete; this is the first section through the lower lip (*l.l.*), the ascending fold of which is the fore part of the *supra-lingual apparatus*. Right and left of these folds, not far from the mucous membrane of the mouth, two large hard cartilages have been caught by the razor; these are the outer front basi-hyals ($b.hy^a.$) (see also Plate 9, fig. 3). These bars turn upwards and outwards, and are sub-pyriform in section, the thick end being uppermost. This 8th section is the first that takes in the lower lip, and we see how truly *Ammocœtine* these Myxinoids are.

---

* The specimen sectioned was older than the one which was dissected, and so the hard cartilage had extended further in the former; this will explain some slight discrepancies between the two sets of figures as to *colour*, and also as to the fineness or coarseness of the *dotting*.

Section 9 (fig. 9).—If this section be compared with the dissections we shall see what an elegant structure the nasal capsule (*ol.*) of *Myxine* is; in my Second Part I shall show that in the Lamprey this organ is a complete *wheel* of plates in section; here it is only half a wheel, and the folds only gently converge; this is the most simple structure of the two. Yet on this simpler platform there is a most curious specialisation of the cartilaginous capsule itself, and also of its vestibule. The accuracy of the *grating* is well shown in the sections. The two lowermost of the *nine* parallel bars are the widest; each bar has its own fold of mucous membrane, and these nearly reach to the common cavity below, which is here very large. Supporting this curious framework, we see the palato-trabecular bands (*p.tr.*, see also Plates 9 and 10); these are hard, oval, and tilted outwards, above. Then, for a short distance in front of the cranial cavity, the floor of the cranio-facial framework is open, being only floored by membrane.

A large tract of palatal tissue intervenes between this weak floor and the roof of the mouth (*m.*), the cavity of which is formed of three fissures, the outer and upper pair being semicircular, and the median, or lower, sub-oblong, but widest above, and having its sides running between deep folds. Above, the median line of the mouth is grooved; below, it is gently ridged; the lateral folds are the fore part of the *supra-lingual* framework. The proper lingual cartilages (*b.hy**.) are now seen to be *four*, instead of *two*, for the median pair have come into view (see also Plate 9, fig. 3); the *apparent distance* between the bars, here, is due to the fact that only the projecting fore end of each was cut through.

Section 10 (fig. 10).—This section is very similar to the last, but is important as showing the fusion of the two median bars (*b.hy.**); in this *old specimen* the fusion is perfect, but in the one dissected there was some appearance of distinctness along the midline, below (Plate 9, fig. 3); here the edges are thicker than the middle, which is gently scooped.

Section 11 (fig. 11).—Several new things come into this section; and here in the middle of the nasal capsule the lower cartilaginous bars are seen to have their own fold, but it is not free, so that there are only seven distinct folds in the sac. The great inferior fontanelle of the cranium bulges gently here, and the tip of the hinder intertrabecula (*p.i.tr.*) is cut across, where it supports the middle of the membranous floor. The bulging of the floor makes a great space for the nasal cavity (*n.c.*).

The palato-trabecular bands (*p.tr.*) are smaller at this part, and evenly oval in section; between the skull and the roof of the mouth there is a considerable web of fibrous tissue.

The form of the mouth cavity here is greatly modified by the horny cheek-teeth—*supra-linguals* (*s.l.t.*)—which are imbedded in a mass of fibrous stroma, and thus the wide mouth becomes a space of three fissures.

The two upper fissures are crescentic, and the form of the median space is a blunted wedge; the floor has two ridges. These sections show that the horny teeth are folds of a continuous epithelium; they are huge *papillæ* with a common horny base, and, distally, have their own cavity.

Under the folds of the mid-line the median part of the supra-lingual skeleton (*s.l.c.*) is cut through; this lies on the fused middle pair of front basi-hyals, which plate is concave under the lesser upper cartilage.

The lateral pairs of the front basi-hyals (*b.hy^a.*) are solid, oval in section, and are further apart from the middle pair than they seem to be in the bird's-eye view. (Plate 9, fig. 3; and Plate 12, fig. 7.)

Section 12 (Plate 12, fig. 1).—This section is through the hind bar of the nasal capsule (*ol.*), and the longitudinal rods of the grating are seen cut across close to the transverse bar. This section is close in front of the membranous cribriform plate, which will be described in my account of *Bdellostoma*, in which (and in *Myxine*) the olfactory nerves, as shown by MÜLLER (II., plate 2, figs. 8–12), pass into the capsule by *five* roots on each side, each root breaking into a pencil of fibres as it enters the capsule; a *Mammalian anticipation.* The palato-trabecular bands (*p.tr.*), and the *handle* of the hinder intertrabecular *spoon* (*p.i.tr.*), are cut through, and are similar to what we saw in the last section. So also are the basi-hyal bars; but, here, the median supra-lingual plate is wider, and the side wings now come into view, to support the cheek-teeth, now showing their distinctness in section.

Section 13 (Plate 12, fig. 2).—This section is very similar to the last, but it is behind the nasal capsule, and through the fore brain (C^1.); a large space is seen between the fore brain and the feeble floor of the skull; this is the posterior nasal (or naso-palatine) canal.

Section 14 (Plate 12, fig. 3).—Here the cranial cavity is at its widest part; the palato-trabecular bands are wider and less tilted at this part, which is in front of the small optic nerves (see Plate 13, fig. 1, *e.*, II.). The hinder intertrabecula (*p.i.tr.*) is cut across in three places, the edges of the *spoon* being caught, laterally. The supra-lingual cartilage (see fig. 8) is here continuous from side to side, being cut through in front of the foremost fissures; it forms a deep trough for the bed of the paired rows of cheek-teeth. Here (see Plate 9, fig. 3) the *four* front bars of the basi-hyal (*b.hy^a.*) are all distinct again, the section being made through the *basi-hyal fontanelle.* In the last *four* sections, the two median bars have been confluent.

Section 15 (Plate 12, fig. 4).—This section is through the fore margin of the subocular fenestra (Plate 10, figs. 1–3, *s.o.f.*), where some soft cartilage divides the *palatine* from the *pterygoid* regions (Plate 9, figs. 1, 2; and Plate 10, figs. 1–3), so that the hard cartilage (*pa.*) here is near the pterygoid; the inner is trabecular (*tr.*). Here the *spoon* of the hind intertrabecula (*p.i.tr.*) is cut across in front of its lateral attachment to the trabeculæ (*tr.*). The area on each side of the naso-palatine canal (*p.n.c.*) is the tissue through which the small optic nerves pass, but they were not caught in this section. The cheek-teeth are cut through nearer their point, and their enclosing cartilage is cut across through the first pair of fissures (fig. 8), so that it is not in *one* piece, as in the last section, but in *three.* The basi-hyal (*b.hy*.) shows some soft cartilage where the two pairs of front bars unite again, behind the median fenestra (Plate 9, fig. 3), in front of the merely double part.

Section 16 (Plate 12, fig. 5).—Here we have a section of the hinder intertrabecula (*p.i.tr.*) where it is confluent with the hind part of the trabeculæ; this is for a very short extent (Plate 10, fig. 3), but the actual union is very instructive, for in these Myxinoids this median bar retains that distinctness from the paired bars, which, in other types, is a very temporary condition. (See in the young Lamprey, Plate 10, fig. 5, *tr.*, *p.i.tr.*) At this point the basis-cranii is perfect, and being across the subocular fenestra (Plates 9, 10, *s.o.f.*) the cranium and pterygo-palatine region of the face are distinct for a short distance.

The supra-lingual skeleton (see also fig. 8) shows the depth of the middle part, and the steepness of the two sides further back across the two first fissures. The basi-hyal is now single (Plate 9, fig. 3, *b.hy*.), but this is down-bent in the middle, where two pieces have coalesced.

Section 17 (Plate 5, fig. 6).—This is also through the suborbital fenestræ (between *tr.* and *pa.*) behind the junction of the hinder intertrabecula with the trabeculæ (*p.i.tr.*, *tr.*). The pterygo-palatine bar (*pa.*) is dipping more and more towards the quadrate region; the lateral supra-lingual plates are narrower, and the basal part broader and deeper than in the last; the double basi-hyal (*b.hy*.) is narrower and deeper.

Section 18 (Plate 13, fig. 1).—In this section, behind the middle of the subocular fenestra (*s.o.f.*), a bundle of fibres is seen emerging from the brain; this is the optic nerve II., with the aborted eye-ball at its extremity. Here the trabecula (*tr.*) is a narrow rod, and the pterygo-palatine (*pa.*) is becoming flat and descending. The naso-palatine canal (*p.n.c.*) is still very wide, but the intertrabecula (*p.i.tr.*) below it is narrowing. This and the two next sections are through the hard cartilage of the hinder bars of the supra-lingual framework; the lateral plates are narrower, and the basi-hyal (*b.hy*.) similar to what was seen in the last section.

Section 19 (Plate 13, fig. 2).—This is the last section through the subocular fenestra (*s.o.f.*); it is very similar to the last, but the intertrabecula (*p.i.tr.*) is much narrower, and the pterygoid (*pg.*) is very solid; the basi-hyal (*b.hy*.) is becoming narrower, and the supra-lingual (*s.l.c.*) shows soft cartilage below, between the two hard bars (see Plate 12, fig 8).

Section 20 (Plate 13, fig. 3).—This and the next are between the first and second fenestræ, and therefore through the "pedicle" (*pd.*) of the pterygo-quadrate region (Plates 9, 10, *pg.*, *q.*); there is soft cartilage here, but with some hardened cells inside it; the trabeculæ (*tr.*) are widening towards the parachordals, and the intertrabeculæ (*p.i.tr.*) under the narrowing naso-palatine canal (*p.n.c.*) are becoming small.

The supra-lingual (*s.l.c.*) is cut through where the hard hinder bars run into soft cartilage above; the upper plate is narrow; the basi-hyal (*b.hy*^{p}.) like the last.

Section 21 (Plate 13, fig. 4).—This section was made through the second fenestra, the trabeculæ (*tr.*) are cut across, and the pedicle (*pd.*) in its hind part; the descending pterygo-quadrate bar (*pg.*) is cut through much further down. The naso-palatine canal (*p.n.c.*) is squarish, and the folds of its lining membrane are shown; under it is the fast narrowing intertrabecula (*p.i.tr.*). Here the elbow of each hard hind bar of the supra-lingual (Plate 12, fig. 8) is cut across outside one of the hinder teeth. The basi-hyal (*b.hy*^{p}.) is now in two pieces, below.

Section 22 (Plate 13, fig. 5).—This section is between the pedicle and the head of the hyomandibular, across the mandibulo-hyoid band (*m.hy.*) and the mandibulo-hyoid fenestra (*m.h.f.*) above, and through the quadrate (*q.*) below; the space between these bars is the second lateral fenestra (Plates 9, 10, *l.f*^{2}.). Inside the upper bar the front face of the auditory capsule (*au.*) is shaved off; these organs are confluent with the narrow fore part of the parachordals (Plate 10, figs. 1–3, *au.*, *iv.*), where the trabeculæ begin in front of the notochord; the intertrabecula (*p.i.tr.*) is very narrow here over the square naso-palatine canal (*p.n.c.*). One of the hinder cheek-teeth is cut through on each side, and part of the cartilaginous wall and the two hind snags. The narrowing hinder basi-hyals (*b.hy*^{p}.) are distinct.

Section 23 (Plate 13, fig. 6).—If this section be compared with the dissections (Plates 9 and 10) the great conformity of the two kinds of preparations will be seen. This and the next are the last sections in front of the notochord; the moieties of the investing mass, or parachordals, form here a mere lip to the lower edge of the *auditory shell* (*au.*), which is seen to be reniform in section, and membranous within, the walls being thickish, and composed of hard cartilage. Here the tip of the *bowl* of the intertrabecula (*p.i.tr.*) is perforated, and thus it is seen in section as two points of soft cartilage over the square naso-palatine canal (*p.n.c.*).

The mandibulo-hyoid bar (*m.hy.*) is a small oval section, a considerable distance from the capsule; much further down there is a curious hook of hard cartilage, and below it, but nearer to it, on the outside, another oval section. The hook is the first pharyngo-branchial (*p.br*^{1}.), at its enlarged end, where it partly occludes the second fenestra (Plates 9 and 10), and the bar below is the narrow neck where the pterygoid passes into the quadrate (*q.*), under the second fenestra. The basi-hyal (*b.hy*^{p}.) is like that of the last section.

Section 24 (Plate 14, fig. 1).—This section sheds light upon the dissections, and is also in turn explained by them.* Here, as in the last, the parachordals are very narrow, turned upwards, and confluent with the auditory capsules (*au.*). Under the square naso-palatine canal (*p.n.c.*) the tip of the *bowl* of the intertrabecula (*p.i.tr.*) is cut across, and near the capsule the mandibulo-hyoid bar (*m.hy.*). At a considerable distance down the side of the throat the hooked cartilage or 1st pharyngo-branchial ($p.br^1$.) is cut across, and below it the quadrate region (*q.*). The basi-hyal ($b.hy^b$.) is still double, and deep.

---

* I must here repeat the fact that these sections show the cartilage to be hard, in places where in the dissections it was soft, on account of the greater age of the specimen made into sections; where any other apparent want of conformity exists between the two sets of observations, it is due to *compression* of the specimen in cutting, for my best specimens were not well preserved, and at the best the pharynx and its *velum* are very elastic and mobile.

Section 25 (Plate 14, fig. 2).—We have now reached the notochord (*nc.*), a mere point here, and not invested by the investing mass, which is still a mere selvedge to the inner and lower edge of the auditory capsule (*au.*). This section is behind the intertrabecula, and it shows the naso-palatine canal (*p.n.c.*) still closed below. The lateral cartilages cut across are the mandibulo-hyoid band (*m.hy.*), the first pharyngo-branchial ($p.br^1$.), and the quadrate (*q.*); below, the basi-hyal is still double, and composed of hard cartilage. The bracket-shaped fold of membrane (above *vl.*, the pharynx is below *phx.*, the dotted lines are wrong) across the roof of the pharynx is the beginning of the "upper velum."

Section 26 (Plate 14, fig. 3).—This section shows the notochord (*nc.*) and the investing mass increasing, and the cavity of the auditory capsule (*au.*) laid open, and in this part the "anterior canal" is enclosed specially by cartilage. The neck and shoulder of the hyomandibular (*hm.*) is first soft, and then hard cartilage. The investing mass has grown beneath the capsule, as well as along its inner edge, below, and thus the hyomandibular which grows from it *seems to be* a mere outgrowth of the capsule.

Section 27 (Plate 14, fig. 4).—The notochord (*nc.*) is now invested by the parachordals; the hyomandibular (*hm.*) is thinner in the middle, here, than at its fore edge, as seen in the last section.

Section 28 (Plate 14, fig. 5).—This is a very instructive section, for here the naso-palatine canal (*p.n.c.*) is opening below, revealing the diagnostic character of the Myxinoids—("Hyperotreta"). The investing mass (*iv.*) now forms a neat trough for the notochord, and is, in reality, continued as a thin but confluent lamina under the auditory capsule (*au.*) where the cartilage is continuous with the soft head of the hyomandibular (*hm.*) By comparing this section with the side view (Plate 9, fig. 2, *hm.*) it will be seen that in this region the bar is soft in three places and hard in two. Inside the lower or symplectic region of the bar (*sy.*), where it runs into the quadrate region, the neck of the large 1st pharyngo-branchial ($p.br^1$.) is seen as hard cartilage. The basi-hyal ($b.hy^b$.) still retains the same character as in the sections immediately in front of it.

Section 29 (Plate 14, fig. 6).—In this section the notochord (*nc.*, *iv.*) is, *for once*, enclosed in cartilage. In the younger dissected specimen (Plate 10, figs. 1, 2,) the investing mass was not perfect anywhere above the notochord—only below (fig. 3). The auditory capsules (*au.*) are perfectly confluent with the basal plate, and here we are behind the head of hyomandibular, so that there is a space before cartilage is shown. The bar cut through is hyomandibular above (just where the opercular process is given off in Teleosteans), and symplectic (*sy.*), below. Inside the bar the 1st pharyngo-branchial (*p.-br*^{1}.) is still hard. The opening of the naso-palatine canal into the pharynx (*phx.*) is very wide here, and the round folds right and left are the sides of the "velum" (*vl.*). The basi-hyal (*b.hy*^{b}.) is beginning now to lose its hard cartilage; the soft cartilage at its edges is the distal part of the descending hyoid bar, the hypo-hyal region.

Section 30 (Plate 14, fig. 7).—The ends of the auditory capsules are here cut through, and the investing mass (*iv.*) is now a thick trough, in which the enlarging notochord lies. The lateral cartilages (*sy.*, *p.br*^{1}.) are the same as the last, but cut through a little further backwards. The double basi-hyal now passes into the large soft elastic 1st basi-branchial above the hard paired cartilages (*b.hy*^{b}.). The soft end of each descending hyoid bar (*h.hy.*) is seen cut across.

Section 31 (Plate 15, fig. 1).—This section is very similar to the last, but is behind the auditory capsules, and the investing mass (*iv.*) is lesser, whilst the notochord (*nc.*) is larger. Below, the hard cartilage of the basi-hyals grows for some extent into the 1st basi-branchial (*b.h.br.*), the hypo-hyal end of the cerato-hyal bar (*h.hy.*) is still seen; it is slightly confluent with the basal bar.

Section 32 (Plate 15, fig. 2).—The notochord is now two-thirds of its average *spinal* thickness; it is almost enclosed by cartilage; this and the last are in the occipital region in front of the 1st spinal nerve (Plate 9, figs. 1, 2, *sp.n.*); here the hind brain (C^3.) begins to be *myelon*. The large flat symplectic region (*sy.*) still comes into section; above it is the inter-hyal bar (*i.hy.*), and, within it, the 1st pharyngo-branchial (*p.br*^{1}.). Below, the hypo-hyal is seen to be distinct from the soft elastic 1st basi-branchial (*b.br*^{1}.), the section of which is U-shaped and thick. The form of the two-lobed velum (*vl.*) is well shown here, with the open channel in which the naso-palatine canal ends.

Section 33 (Plate 15, fig. 3).—The notochord (*nc.*) has now acquired nearly its full size, and still it has two points of cartilage upon it, the extreme ends of the parachordals (see figs. 1, 2, *iv.*). A good distance down we get the upper band of the branchial basket-work cut through where the outer descending hyoid passes free from the hyo-mandibular region; this is the inter-hyal region (*i.hy.*). This bar re-appears again below at the bottom of the cerato-hyal as the hypo-hyal region (*h.hy.*); in some of the sections not drawn these two points passed into each other, the compression of the head curved the bar so as to make the razor pass through it in two points; and the same cause has forced the "velum" down, so that both in this and the next, the cartilages in it (*p.br*^{1}., *p.br*^{2}.) are lower down than in an undisturbed state. Between these small points we see the leafy part of the symplectic (see Plate 9, figs. 1, 2, *sy.*), still coming into view in section. The 1st basi-branchial (*b.br*^{1}.) is now a deep trough of *vacuolar* tissue, with the hypo-hyals (*h.hy.*) at its edge.

Section 34 (Plate 15, fig. 4).—This is from a considerable distance back, so that all the cartilage seen in it is mainly that of sections of the terminal rays of the basket-work (*e.br*^{1}., *p.br*^{1,2}.), with the very last part of the hyoid bar (*h.hy.*), and, above, the upper part of the 1st branchial (*e.br*^{1}.) is cut through twice. The 1st basi-branchial almost closes upon the median bands (belonging to the huge lingual muscles) that lie inside it. This section was made between the 1st and 2nd spinal nerves (Plate 9, figs. 1, 2) (*sp.n.*), and here the notochord (*nc.*) is of full size, and has no cartilage around it, whatever; the parachordals are the only *paraxial* cartilages developed; and, as in the larval Lamprey, there are no rudiments, even, of vertebræ; here, for C^3., read *my*.

Beneath the huge lingual muscles, the intra-branchial skeleton breaks out again; there (Plate 9, fig. 4) the 2nd basi-branchial (*b.br*^{2}.) reappears as a band of hard cartilage, broadish in front, and narrower behind, it is ventrally placed in relation to the first two branchial pouches; it does not support them, but lies under the "raphe" of the hinder part of the massive muscular apparatus of the tongue (*l.m.m.*).

The foregoing are all the skeletal parts I can find in this Fish, which in some respects is developed more in conformity with the higher Fishes—Cartilaginous or Bony—than the Lamprey, and in others is so very rudimentary; altogether, it evidently belongs to the *Ammocœtine* type, although greatly specialised in its own way, to its own ends.

The sections just described will be equally useful for both *Myxine* and *Bdellostoma*, for this latter larger Fish differs only in non-essentials from *Myxine*; my description of the former will merely relate to dissections, and to a general longitudinally-vertical section of the Fish.

On the skeleton of Bdellostoma Forsteri.*

On the cranio-facial apparatus of the adult Bdellostoma Forsteri.

The *theca cranialis*, or dura mater, in the hinder half, and the nasal capsule in the front half of the cranium (Plates 16, 17), have to be removed before the proper framework can be seen from above; the lingual apparatus has to be dissected from the lower part of the head before the basal part can be seen. Neither in the adult of these two types, nor in the embryo of the somewhat higher Lamprey, do we see any other explanation of the *pre-pituitary* part of the cranium than that of an outgrowth or foregrowth of the axial part of the skull. And yet the *pro*-chordal part begins first, and is larger, often much larger, than the *para*-chordal; moreover, in most low forms the prochordal part is developed first. The notochord is very uniform in bulk along the spinal region in these large long Fishes, only gradually lessening in the caudal region. In the head, this rod (Plates 16, 17, *nc.*) suddenly becomes conical, and ends between the middle of the auditory capsules (*au.*) so that this part of it is only one-tenth the length of the entire skull. Of course in the embryo the relative length was much greater. In the embryo of the Lamprey, as I shall show in my Second Part, it is half as long as the entire skull, and in the youngest chondrocranium figured by me in *Lepidosteus* (Phil. Trans., 1882, Plate 30, fig. 3) it is *three-fifths* the length of the skull.

---

* Dr. GÜNTHER informs me that there is but one species of this Fish, and that the kinds called *B. Forsteri* and *B. heterotrema*, by MÜLLER, are merely varieties of the same species. Dr. GÜNTHER's description of the two Myxinoid Genera is as follows:—

"MYXINE.—One external branchial aperture opening only on each side of the abdomen, leading by six ducts to six branchial sacs.

"BDELLOSTOMA.—Six or more external branchial apertures on each side, each leading by a separate duct to a branchial sac." ('Study of Fishes,' p. 695.)

MÜLLER, I., plate 7, fig. 3, gives a figure of *Bdellostoma* with *seven* pouches on the left side, besides the "ductus œsophago-cutaneous," and only *six* pouches on the right side. I found only six pouches on each side in my two specimens; for *plans* of these remarkable branchial organs see the same plate in MÜLLER's Memoir.

So that we see that in these low Myxinoids—the lowest known Vertebrata—the chondrocranium, during development, must have undergone a large amount of change, and we seem to be almost as far off as ever, in these types, in their adult state, from finding an archaic skull. Embryonic chondrocrania, in various *Ichthyopsida*, are our best guides. The investing mass (Plate 17, figs. 2, 3, *iv.*) is complete for a short distance, both above and below, and it projects, as hard cartilage, a little distance behind the auditory capsules, thus forming a rudimentary basi-occipital; but there is no occipital arch or ring. This short parachordal tract is round behind, and deeply notched in front, for the trabeculæ begin opposite the middle of the small auditory capsules. Those bands are only free from surrounding parts for a very short distance, being first (at their parachordal roots) continuous with the infero-internal edge of the auditory capsules, then on the outside with the pedicle, and in front of the short oval subocular fenestra (*s.o.f.*), for the remaining two-thirds of their length, they are continuous with the palatines (*pa.tr.*). This latter essentially compound part is very solid, and for the last sixth of the skull-length the two sides are completely united, so as to form a very solid ethmoidal region (*eth.*). The whole roof is unfinished, being only closed by the dura mater, but the depth of the auditory capsules, and the thickness of the palato-trabecular bars, give a trough-like character to this flat, unfinished skull. Below (Plate 17, fig. 3), the main bulging is formed by the hinder intertrabecula (*p.i.tr.*) and the auditory capsules, which project almost as much below as above; the skull proper is gently convex in the fore part, and in front bends downwards a little. The so-called "pituitary space," or lower cranial fontanelle, reaches from the middle of the auditory capsules to the ethmoid, and is lanceolate, but its narrow fore end is rounded. About half this membranous space is floored by the soft convex hinder intertrabecula (*p.i.tr.*), an additional cartilage, two-thirds the length of the skull, and which reaches from the trabecular roots to the ethmoidal commissure. It is a *ladle*, with its handle dilated in front, and its bowl produced behind, into a short second process or beak; the bowl occupies about a fourth of its length, and is near the hind part. The whole upper part is hollow (Plate 17, fig. 2, *p.i.tr.*), and at the middle of the bowl a short side band runs into the trabecula right and left, these bars being soft for a short space, where the junction takes place, and at this part the trabeculæ bend inwards. Exactly right and left of the *bowl* we see the regularly oval suborbital fenestræ (*s.o.f.*), each about half as large as the bowl, and having its long axis parallel with that of the skull. The front part of the skull is elegantly *ox-faced;* the bovicorn outgrowths are the soft prepalatine bars (*pr.pa.*); they are almost as long as the common palato-trabecular bar next behind them, and their length and distance apart are about equal. They have, hung about them, four pairs of *lesser horns,* three pairs acute, and the fourth double and *cervicorn;* these are the cartilages of the barbels (*n.bb.*, *o.bb.*). The rest of the face is a kind of lattice work, ending behind in free cervicorn processes. The second median element of the skull—the front "intertrabecula" (*a.i.tr.*)—is spindle-shaped and compressed; it is composed of hard cartilage, as in *Myxine;* it overlies the ethmoid in its hind half, and the nasal sac lies over it. The lower margin of the palato-facial growth is convex where the great prepalatine "horn" grows out, then concave, but is obliquely descending in the orbital region; the deepest part of the palato-quadrate tract is directly below the middle of the auditory capsule, and here the quadrate condyle *should* be found; there is none, and no mandibular rod. The lower edge of the cartilage remains soft (Plate 16, fig. 1, *q.*), and so also does the pedicle of the suspensorium (*pd.*); but there is no soft cartilage under the fore part of the subocular fenestra (*s.o.f.*) such as we saw in *Myxine* (Plates 9 and 10). The second lateral fenestra (*l.f*^{2}.) is nearly twice the size of the one in front of it; it is heart-shaped, having a round process of cartilage growing into its hind margin. A second soft "pedicle," the head of the hyomandibular (*hm.*), is seen under the hind part of the auditory capsules; between these there is a small upper fenestra (Plate 17, fig. 1, *m.hy.f.*), whose lower boundary is a thick bar of hard cartilage (*m.hy.*), the shoulder of the hyomandibular (*hm.*). The fore part of this bar is continuous with the suspensorium (its metapterygoid region), whilst, behind, it ends in soft cartilage, the inter-hyal region (*i.hy.*). The upper part of the hyomandibular in osseous Fishes is mostly very broad, projecting over the short free metapterygoid in front, and growing backwards as the "opercular process." This upper hyoid region finishes the second fenestra, behind, sending inwards a round lobe, and being also sublobate behind in three places. Below and above, the small lobes of hard cartilage pass into the soft kind, above in the inter-hyal region, and below, in the symplectic (*sy.*). From the inter-hyal region the descending epi-cerato hyal band, two-thirds the width of the hard band in front, descends *over* the hinder or third or largest fenestra (*l.f*^{3}.), the hinder half of which is enclosed by the arcuate and spiked 1st epi-branchial (*e.br*^{1}.)[*] There is a notch, below, between the arrested quadrate (*q.*) and the lower part of the symplectic region (*sy.*) The cartilage is all soft here, and above the junction of the two kinds the symplectic region sends a spur backwards partly filling in the lower part of the space. The long hyoid bar (*e.hy.*, *c.hy.*) is sigmoid above, and then slants forwards and downwards to its hypo-hyal region (*h.hy.*), where it is continuous with the basal bar (*b.hy*^{b}.). The lower boundary of the large posterior membranous space (*l.f*^{3}.) is

---

[*] See Plate 17, fig. 1; in fig. 2, and in Plate 16, fig. 1, this part is lettered *c.br.* by mistake.

formed by the passing of the symplectic into the 1st epi-branchial (*sy.*, *e.br*^{1}.); this bar becomes dilated behind, has a sinuous margin in front, and sends backwards two sharp spikes or rays (non-segmented branchial rays). But this enclosing arcuate spiked bar is only the middle of the large 1st branchial arch; it has a very long pharyngo-branchial piece above (*p.br*^{1}.) and a long slender cerato-branchial (*c.br.*) below, both these rods are directed backwards and end in long, sharp styles, and both are *f*-shaped; the lower is a part *nearly* segmented off from the rest of the basket-work, still it is attached, below, to the basal bar, behind the descending hyoid. The 1st pharyngo-branchial (*p.br*^{1}.) can be seen from the side filling in the hind and lower part of the middle fenestra, and serving to give "origin" to a fan-shaped series of muscular fasciculi (Plate 16, fig. 1). That part is confluent with the hyomandibular, and is hard; the rest is soft cartilage and passes upwards a little, and then directly backwards, being enclosed in the edge of the "velum" (Plate 16, fig. 6; and Plate 17, fig. 1, *vl.*). These sigmoid rods are continuous on their inside, a little in front of their middle, with the fore end of another pair of rods, similar but smaller, and their serial homologues; these are the 2nd pharyngo-branchials (Plate 17, figs. 2, 3, *p.br*^{2}.); they have no descending part. Each bar, towards the middle, is bent towards its fellow, like the larger first pair, and the two are twice united by a cross band. The front commissural band sends forwards a pair of three-rayed rods spreading out over the others and looking forwards; and from its hind margin it gives off a single median rod, which passes directly backwards over the hinder commissure, and then breaks up into two larger sub-terminal and two smaller terminal rays. These four rays, and the points of both pairs of main pharyngo-branchials (*p.br*^{1}., *p.br*^{2}.) end in the transverse crenate hind margin of the great upper pharyngeal "velum" (Plate 17, fig. 1, *vl.*). This structure is much like that seen in *Myxine* (Plate 15, fig. 6), but in that Fish the 2nd is free from the 1st pharyngo-branchial, and the median bar of the former is absent.

The complexity of this reticulation of cartilage suggests the presence of a 3rd pharyngo-branchial rudiment, but I am not certain of its existence.

The huge basal bar is quite like that of *Myxine* (Plate 16, figs. 1, 2, 6, *b.hy.*, *b.br*^{1}.), the front part, for more than a third of the whole length, being composed of hard cartilage, and the rest of *vacuolar tissue;* this part is the 1st basi-branchial (*b.br*^{1}.), and the other basi-hyal (*b.hy.*). This is a curious piece of special "hypertrophy," for the normally single basal bar is composed of two bars behind, and four in front, all large, solid bars, oval in section. The outer of the front pieces are the largest; a small fontanelle is seen where the *six* pieces meet, and they are all connected together by tracts of soft cartilage. Looking at the structure as a whole,—first, quadruple, then double, and then single, and composed of four *varieties* of connective tissue,—we see, at once, that it is merely an enormous development of the common "basi-visceral" element. It is hollow above, all along, as in *Myxine;* in front, to hold the secondary trough-shaped cartilage (supra-lingual), and behind, to receive the tendons of some of the muscles that work the whole lingual machinery.

Close behind the hard cartilage of the basi-hyal, the hypo-hyal end (*h.hy.*) of the descending hyoid bar is there continuous both with the hard and the soft cartilage; and behind it, in its *axil*, the lesser bar, or 1st cerato-branchial (*c.br*^{1}.) is attached,—semi-confluent. The 2nd basi-branchial (Plate 16, fig. 3, *b.br*^{2}.), is a thickish rod of hard cartilage serving for the attachment of the oblique muscular mass of the lingual apparatus; it is broad in front and narrow behind, and moderately thick. **MÜLLER**, *who let nothing escape him*, figures a triradiate tract of soft cartilage on the "œsophago-cutaneous duct" (I., plate 7, fig. 5). I find a similar piece (Plate 16, fig. 7, *d.œ.c.*). This is extremely interesting and instructive, for it is all we have in this type—(I do not find it in *Myxine*)—of the huge "extra-branchial" basket-work of the Lamprey, which can already be seen in embryos one-fifth of an inch in length. Thus, if the Myxinoid is a sort of *Ammocœte*, it is an Ammocœte with a difference.

On the supra-lingual apparatus of Bdellostoma.

In these structures, again, we have a curious *generic* difference between *Bdellostoma* and *Myxine;* this series of intra-visceral arches is, however, only gently modified in the former from that of the latter (see Plate 12, fig. 8; and Plate 16, fig. 5).

Here, there is no differentiation of the median bar; the middle, in front, projects forwards as a triangular tongue of cartilage, but not behind the last lateral bars; the middle, there, is merely a soft narrow tract. The first pair of partly-segmented arches is the largest in this type, only the margin, all round, is soft; it ends in two soft incurved horns. The second pair of bars is soon lost in the third, which are almost as large as the first, and are quite hard, except the middle, or connective tract. I see no horny points in the front part of the common ligamentous tract in front, such as we saw in *Myxine* (Plate 12, fig. 8). A deep fissure divides the first pair of arches from the other two; they are only separated across the middle for one-third of their extent. The richly golden, lanceolate teeth (Plate 16, figs. 4 and 6), show two rows, right and left, of more equal teeth than in Myxine (Plate 12, fig. 7); there are *eleven* in each of the four rows; I counted seven on the outer, and nine on the inner rows in *Myxine*. The single upper tooth attached to the ethmoidal region of the skull is a very large "canine," hooked backwards (Plate 16, fig. 6; and Plate 17, fig. 3, *et.t.*).

On the sense-capsules and barbels of Bdellostoma.

The auditory capsules (Plate 16, figs. 1, 6; and Plate 17, figs. 1–3, *au.*) in this type also are very small, and composed of hard cartilage; they are quite confluent with the contiguous parts of the skull; seen from below (Plate 17, fig. 3, *au.*), they are of a full oval form, and their long axis is almost parallel with that of the skull, but looking a little inwards in front. Above (figs. 1 and 2, *au.*) they are reniform, on account of the deficiency of cartilage in the great "meatus internus;" these figures fail to show the involution of cartilage round the anterior canal as seen in the *sections* of these parts in *Myxine* (Plate 14, fig. 3, *au.*). The "meatus" are seen almost directly from above (fig. 2), and they are margined on their inner edge by the parachordals as they pass into the trabeculæ (*iv.*, *tr.*). The proper olfactory capsule (Plate 16, figs. 1, 6, *na.*; and Plate 17, fig. 1, *na.*) is only gently modified from that of *Myxine;* its fore margin is partly united with the last ring of the outer nasal tube (*e.n.t.*). There are only eleven imperfect annuli in *Myxine* (Plate 10, fig. 1 *e.n.t.*), in this type there are twelve, but these are not quite distinct, as in the Hag Fish; here, the first three are united, and have one small and two large fenestræ; the seventh and eighth are joined in the middle, and the twelfth, partially, with the proper capsule (*na.*). So unlike is the structure of the lips in these, to what is seen in any other types, that nothing but *re-dissection* enabled me to understand MÜLLER's perfectly accurate figures; especially was this the case in the "barbels."

Here (Plate 16, fig. 1; and Plate 17, figs. 1–3, *n.bb.*, *o.bb.*) they are much more modified than in *Myxine* (Plates 9 and 10). The upper pair (1st nasals) are united across the mid-line by a strong commissure which passes under the top of the front intertrabecula (*a.i.tr.*), and the second pair (2nd nasals) are attached to the first where they pass into the cross band.

The upper orals (*o.bb.*) are triradiate, they send an upper curved ray to join the two nasal palpi, and from their proper palpal part which grows forwards they send backwards a lobe over the 4th (or 2nd oral). This latter cartilage is bent forwards, and then sends out three short snags; its upper horn fits into the angle of the 1st oral, and its hinder horn turns backwards and downwards, nearly reaching the front of the "supra-lingual" apparatus. If we turn to the figures of the barbels in their *undissected* state, we shall see reason to believe that they all belong to the *upper lip* (Plate 8, figs. 7–9; Plate 13, fig. 7—*Myxine;* and Plate 15, fig. 5—*Bdellostoma*); in the large kind the 2nd orals are but little produced as barbels, but form an evident fold in front of the lower lip. Thus, in the fullest development of a *Myxinoid's* mouth there is no more promise of what the transformed Lamprey shows in the *lower lip* than in its own larva—the *Ammocœte.* As *Marsipobranchii*, the "Myxinoids" are more specialised, in some important respects, than the "Petromyzoids;" but as *suctorial* Fishes they are altogether below them, bearing to them a sort of *quasi-larval* relation.

Description of a longitudinally vertical section of the head of Bdellostoma.

In this section (Plate 16, fig. 6) we see many things brought into view which may help in the comprehension of this remarkable type of cranio-facial skeleton. Muscular segments and their interseptal fibrous tracts are found running over the brain up to the nasal sac (*na.*, *ol.*); the brain mass (C.) insensibly passes into the *myelon* (*my.*), which latter is supported by the large notochord (*nc.*). This figure shows the *vacuoles* ending some distance behind the thick sheath; this appearance is due to the fact that the section was not quite in the middle: the proper structure of the notochord ends opposite the middle of the ear capsules. The capsule (*au.*) is shown in section near the meatus, so that its thickness appears greater than it is in reality, as the parachordal cartilage thickens it on the inside. The folds of the nasal capsules (*na.*, *ol.*) are brought into view, and the cartilages (*na.*), both of the capsule itself (*ol.*) and of the external nasal tube (*e.n.t.*) are cut through, very near the mid-line. A continuous passage is seen from the external opening (*e.n.*) of the nasal passage (*n.p.*) to the fringed lips of the naso-palatine canal (*p.n.c.*) which opens at the mid-line at the fore part of the velum (*vl.*), here shown in section, with a point of cartilage in it, here and there, caught by the razor. The size of the cavity and the character of the folds inside it, of the fore part of the naso-palatine canal (*p.n.c.*) are seen in this section, and also that these lie *on the floor of the skull*, between the hind intertrabecula (*p.i.tr.*) and the brain (C.) The opening *out of the skull* is behind that median cartilage, between the produced "bowl" of the "spoon" (Plate 17, fig. 3, *p.i.tr.*) and the beginning of the trabeculæ (*tr.*, *iv.*). Another cavity—a space between the hinder intertrabecula and the roof of the mouth—is also seen. This is evidently artificial, and caused by the tearing away of the mucous membrane of the palate from the hinder intertrabecula. A curious coiled valve is seen behind these two openings, under the fore part of the velum, at the beginning of the pharynx; a little in front of this fold, the proper oral cavity (lined with *epiblast*, the pharynx being lined with *hypoblast*) ends. At this part, the entrance of the proper pharynx, the passage is a series of slits or fissures (see the *sections* of the skull of *Myxine*, in Plate 13). Somewhat *left* of the mid-line, this section shows only part of the front intertrabecula (*a.i.tr.*), and thus the whole of the great median tooth (*et.t.*), and the ethmoid (*eth.*), a little to the left, is seen under it. Both the ethmoid and the base of the tooth are enclosed in a special fold of membrane over the oral entrance (*m*). That space would be large, but *two additional lingual masses*, the paired rows of teeth (*s.l.t.*) and their membranous and cartilaginous settings (*s.l.c.*), fill the greater part of the space between the basi-hyal and the palatal membrane. This section being a little to left of the mid-line, shows the inner edge of the *left* bars of the basi-hyal (*b.hy.*), and as the middle bars of the front or quadruple part are shorter than those outside, the cartilage is seen to stop short of the fore end of the under face (lower lip). These cartilages are enveloped in the muscular masses that move the tongue. The upper or ethmoidal tooth (*et.t.*) is seen to turn its point backwards; in the figure it is *in front of* the paired rows of supra-lingual teeth (*s.l.t.*), but the powerful muscular apparatus works so as to make it antagonistic to the lower teeth, generally, which can be made to move backwards and forwards, and from side to side. This whole muscular mass, in my larger specimen, is sub-cylindrical, six inches long, and one inch in thickness. The reader is referred to MÜLLER's works for a description of the whole apparatus.

On the cranial nerves of Bdellostoma.

For a detailed account of these, and also of the whole nervous system, the same excellent author is referred to; but I have given an outline figure of the skull with the cranial nerves shaded, to help in the determination of the skeletal parts. My own dissection of these nerves was made with the help of Müller's work ('Neurologie,' III.). I made no attempt to find any filaments of the 3rd, 4th, and 6th. The vagus nerve (Plate 10, fig. 4, X.) probably contains the fibres that in higher forms are given off as the separate glosso-pharyngeal. Müller does not figure that nerve as distinct, nor can I find it. But the vagus is very large, and as its proper related structures are removed far backwards, passes directly backwards at right angles to the spinal nerves (*sp.n*$^{1-3}$.). The vagus emerges behind the auditory sac (*au.*), over the short parachordal.

The 8th or auditory nerve is not figured; it passes into the auditory capsule through the great meatus internus.

The 7th nerve (VII.) is shown; it finds its way out of the skull in front of the auditory capsule, between the "pedicle" and the head of the hyomandibular (fig. 2, *pd.*, *hm.*), and turning backwards, burrows under the "shoulder" of the hyomandibular, escaping again behind the *symplectic* region—the hind boundary of the second fenestra—and passes down with, and in front of, the descending epi-cerato-hyal bar (*e.hy.*, *c.hy.*).

The 5th or trigeminal nerve (V.) is immense, and at first sight rather difficult of interpretation. I follow Müller's notation, finding nothing in it to criticise. It is seen emerging in front of the auditory capsule over the pedicle (*pd.*). It then breaks up into three branches, two of which pass *over* the subocular fenestra (*s.o.f.*), whilst one pierces that membrane behind, and passes *under* the palato-quadrate cartilage. The 1st branch, the orbito-nasal (or *ophthalmic*, V^1.), is very large, and soon breaks up into a lesser outer and a larger inner branch. The inner branch then becomes trifid. The "upper maxillary," or second branch of the trigeminal (V^2.) is *considerably less* than either of the three branches of the ophthalmic; it runs over the subocular fenestra, and the palato-quadrate cartilage. The "inferior maxillary," or third branch (V^3.), is as large as the ophthalmic, and as soon as it has passed through the suborbital fenestra it breaks up into four branches, which pass to the lower parts of the head in front.

The optic nerves (II.) are about a fourth the size of the small maxillary nerve; they pass under the ophthalmic (orbito-nasal), and are distributed to the arrested eye-ball (*e.*), enclosed in the much larger *fat body* (*c.a.*).

The olfactory nerves (I.) pass through the membranous "cribriform plate," which is in two divisions and oblique. The huge olfactory lobes give off each *five nerves*,* and these, *beginning to bifurcate*, pass in a sub-horizontal row, right and left, to the olfactory folds (*ol.*); here there is a most remarkable anticipation of the Mammalian olfactory nerves and *cribriform plate.* If we now compare the diagram (Plate 17, fig. 4), and the meagre description just given of the cranial nerves of this great Myxinoid, we shall find many things become clear that have been for a long time confusing to the students of these types; for there has, apparently, been much *concrescence* and much *suppression* in the development of the cranial nerves in these remarkable Fishes. In the Lamprey, also, there are some very abnormal characters. The right determination of the skeletal parts is largely dependent upon a true knowledge of the cranial nerves, and, *vice-versâ*, they have to be considered in their relation to the supporting skeleton.

---

* The outer or fifth bundle of the olfactory nerve lies somewhat under the fourth, and is not shown in the figure.

Müller II. ("Gehörorgans," plate 3, figs. 3, 4, 5) gives upper, lower, and side figures of the brain of *Petromyzon fluviatilis*, and he enumerates the following nerves going off from it right and left, viz.: I. Olfactory (large and single); II. Optic (moderate size); III. Oculo-motor (very small); IV. Trochlearis (still smaller); V. Trigeminus; VI. Facialis; VII. Acusticus; VIII. Vagus; IX. Hypoglossus.

In the second plate figures are given of the brain of *Bdellostoma* (figs. 8, 9) and *Myxine* (figs. 11, 12).

In these closely related types we have the following cranial nerves given by Müller, viz.:—

I. Olfactory (in five main nerves on each side, and these also each breaking into a small pencil of branches); II. Optic (very small in *Bdellostoma*, but paired; much smaller and only drawn on the *right side* in *Myxine*); III. Trigeminus (very large); IV. Facialis; V. Acusticus; and VI. Vagus (very large).

In his paper (III.) on the 'Neurologie' of the Myxinoids, Müller (plate 2, figs. 4, 5) gives the cranium and its nerves in *Bdellostoma* from above and below. In the upper view the optic nerve is shown passing under the ophthalmic nerve, which is drawn with its first bifurcation. The larger part of the nerve is seen penetrating the suborbital fenestra, and in the lower view this lower part (3rd branch) is seen broken up into four branches, the second of which is re-split. But in the upper view there is also, behind the ophthalmic (1st branch), a small nerve passing over the palato-quadrate cartilage; this he does not name.

But in the next plate (III., figs. 2 and 3) we have this 2nd branch of the trigeminal figured on both sides. In the upper view (fig. 3) it is seen as passing over the cartilage bounding the suborbital fenestra, and in the side view (fig. 2) it is shown as running forwards along the upper surface of the palato-quadrate nearly up to the beginning of the soft "pre-palatine horn." Here it is called "Vorderen ober Ast des Trigeminus," whilst the large branches that grow from the stalk that pierced the fenestra are called "Unter Aeste desselben,"—the lower branches of the same nerve. In the upper view (fig. 3), where the 1st and 2nd branches (only) are drawn, he calls this small nerve "Hinterer oberer Hautast des Trigeminus;" whilst the branches of the great 1st division (Ophthalmic), "Vorderer ober Ast des Trigeminus," he calls "1, Hautast; 2, Nasenast; 3, Oberer Endast; and 4, Unterer Endast."

That there is no mistake here I feel certain; my own dissection shows the same pair of nerves, namely, the *small*, proper, 2nd branch of each trigeminal.*

Now in these Myxinoids we miss the 3rd, 4th, and 6th cranial nerves; also the glosso-pharyngeal or 9th nerve as a separate nerve.

In *Petromyzon*, also, MÜLLER misses the 6th or "abducens" (II., plate 3, figs. 3–5); the "upper maxillary branch" of the trigeminal is small and inconspicuous but quite as large as in *Bdellostoma.* This being the case we have an explanation of what has been a difficulty with us for years; Professor HUXLEY† speaks of "a singular anomaly" in both *Petromyzon* and the Myxinoids, in that "Both the second and third divisions of the trigeminal nerve pass through the subocular membrane, and therefore on the ventral side of the (subocular) arch;" but this error was corrected by him soon afterwards.

That the *arch* and the *membrane* (fenestra) are both the exact counterparts of what we find in the various Batrachian larvæ I cannot doubt; and there is no doubt now, of the existence of a 2nd branch to the trigeminal in *Petromyzon;* and, as we have just seen, such an *upper* branch does exist in *Bdellostoma*, between the huge 1st and 2nd branches.

Summary and conclusion of Part I. (Myxinoids).

In seeking for light upon the primordial condition of the Vertebrata one naturally looks to such forms as the Myxinoids, for in these types, even in the adult state, there are neither limbs nor vertebræ, and no distinction between head and body, except the rudiments in the head, of a cartilaginous skull, *a continuous* structure, not showing the least sign of secondary segmentation, and by far the greater part of which is in front of the notochord, or axis of the organism. But here our *gradational* work agrees with the *developmental,* for the continuous skull bars constantly arise before the secondary cartilaginous segments that are formed between the "Myomeres" behind the head. Evidently, therefore, the early "Craniata" grew supports to the enlarged and sub-divided front end of the neural axis long before anything beyond strong fibrous septa were developed between the muscular segments of the body. As for the linear growth, and the less or greater extension backwards of the main organs, —circulatory, respiratory, digestive, and uro-genital—that in the variation of the primordial form was a thing to be determined by the life and surroundings of the type. "Thereafter as *they* may be," was the tentative idea in this case.

Certainly in the Marsipobranchs and in their relations the larval "Anura," we have the most archaic "Craniata" now existing; in these the organs may be extended far backwards in a vermiform creature, as in these low Fishes, or kept well swung beneath the head; the body and tail, together, forming merely a propelling organ, as is seen in Tadpoles, especially the gigantic Tadpole *of Pseudis*.

---

* See also RETZIUS, plates 1 and 2, and note to p. 42, in Part II.

† See "On the Nature of the Cranio-facial Apparatus of *Petromyzon*" (Jour. of Anat. and Phys. vol. 10, p. 423, a paper to which I am exceedingly indebted in working out these types).

Thus we see that in low, limbless types there is no necessity for the development of more than fibrous *metameres*, but the vesicular brain, the suctorial lips, the purse-shaped gills, and the special organs of sense, these all call for support from some tissue more dense than a mere fibrous mat or web. In the *Myxinoids* we see that four special modifications of the connective tissue series are developed for the support of the properly *cephalic* organs, and two of these for them, only, so that these Fishes are chordate and craniate, but are not *vertebrate*, if we stick to the letter. At first some disappointment is felt, after careful study of these types, for notwithstanding the low level in which they *remain*, they are mere specialised Ammocœtes, keeping on the same "platform" as the larval Lamprey; yet some parts of their organisation do undergo a marvellous amount of transformation, and are, indeed, as much specialised in conformity with their peculiar habits of life as *any Vertebrates whatever, the highest not excepted.*

Yet, on the whole, the Myxinoids are a sort of *Ammocœtine* type, whilst the transformed *Ammocœte*, the Lamprey, comes nearest to the untransformed Frog or Toad,—the Tadpole. But the mere putting of this shows (*suggests* at any rate) what *losses* the fauna of the world has sustained during the evolution of the "Craniata." For us, *now*, the Myxinoids, Petromyzoids and Anurous Amphibia must all be kept "within call" of each other; but the types that have been culled out, between them, cannot be numbered.

Some other types of Fish are evidently the descendants of primordial "Marsipobranchs," notably *Lepidosteus*, the development of which has lately been made out and the results published in the Philosophical Transactions (1882, Part II.).

But the *Chimæroids* and *Dipnoi*, and, what is still more important, the *Myxinoids* themselves, have still to be followed through their early stages; if the present paper is of any value to the Morphologist, one on the embryology of these low forms would be worth many such papers.

The Myxinoids keep on the low platform of the larval Lamprey (or *Ammocœte*) in the following particulars, namely :—

a. The notochord has no paired cartilaginous vertebral rudiments in the spinal region.

b. The trabeculæ end in the ethmoidal region without growing forwards into a cornu (or two cortinuous cornua).

c. There are merely "barbels" round the mouth; no perfect *labial cartilages.*

d. The last character involves another, namely, that the special armature of horny teeth attached to the labials in the adult *Petromyzon* is absent.

e. The organs of vision are very feeble, and probably almost useless; in the *Ammocœte* they are arrested for a time.

f. The cranium is a mere *floor*, without side-walls or roof.

The Myxinoids come near to the adult Lamprey in the following particulars, namely :—

a. There are developed outside the skull proper, but not segmented from it, palatoquadrate and hyoidean cartilages.

b. There is a very large median cartilage belonging to both the hyoid and branchial regions.

c. The cranium acquires a floor by the development of a special hinder intertrabecula.

d. There is a large median cartilaginous olfactory capsule.

The Myxinoids go beyond even the adult Lamprey in the following characters, namely :—

a. The facial basket-work is much more perfect, and as this is a generalised condition of the true *intra-visceral* system of cartilages, it is a very important character. There is not only an equal development of the "*suspensorium*," but the *suspensorial part* of the hyoid is developed also (it is suppressed in the Lamprey); and there is (in *Bdellostoma*) a large complete 1st branchial arch, and in both kinds pharyngo-branchial rudiments of the 2nd branchial arch.

b. The respiratory pouches are much more specialised, being carried far back under the spine.

c. There is not only a very distinct sub-cranial intertrabecula, but also a large precranial or nasal median cartilage of the same nature.

d. The opening to the median olfactory sac is not a mere short membranous passage, but a long tube, encased in a series of cartilaginous (imperfect) rings.

e. Correlated with the non-development of the suctorial labial apparatus, there is an enormous development of the *lingual*, this basal bar becoming not only double, but in front quadruple; and the "supra-lingual cartilages," which are very small in the adult Lamprey, and carry only one pair of rows of small recurved teeth, in the Myxinoids are very large, and carry two pairs of rows of large teeth, with the addition of a median ethmoidal antagonist tooth.

Lastly, the greater development of the intra-visceral cartilages is correlated with the suppression of the extra-visceral basket-work, seen both in the larval and adult Lamprey, and also in the larvæ of the "Anura," generally.

EXPLANATION OF THE ABBREVIATIONS.

The Roman numerals indicate nerves or their foramina.

a.i.tr.	Front intertrabecula.
au.	Auditory capsule.
bb.	Barbels.
b.br^{1,2}.	Basi-branchials.
b.c.f.	Basi-cranial fontanelle.
b.h.br.	Basi-hyobranchial.
b.hy^{a}.	Front basi-hyal.
b.hy^{h,p}.	Hind basi-hyal.
b.p.	Buccal pouch.
br.a.	Branchial artery.
br.c.	Branchial canal.
br.d.	Branchial duct.
br.p.	Branchial pouch.
C^{1,2,3}.	Cerebrum.
c.a.	Corpus adiposum.
c.br.	Cerato-branchial.
c.hy.	Cerato-hyal.
c.tr.	Cornu trabeculæ.
cl^{1,2,3}.	Clefts.
d.m.	Dura mater.
d.œ.c.	Ductus œsophago-cutaneus.
e.	Eye
e.br.	Epi-branchial.
e.f^{2,3}.	External (*lateral*) fenestræ.
e.hy.	Epi-hyal.
e.n.t.	External nasal tube.
e.pa.	Ethmo-palatine.
eth.	Ethmoid.
et.t.	Ethmoidal tooth.
f.	Fenestra.
h.	Heart.
h.hy.	Hypo-hyal.
hm. (and *h.m.*)	Hyomandibular region.
i.vl.	Inferior velum.
l.f^{2,3}.	Lateral fenestræ.
l.l.	Lower lip.
l.mm.	Lingual muscles.
m.	Mouth.
m.h.c.	Mandibulo-hyoid-cartilage.
m.h.f.	(*m.hy.f.* and *h.m.f.*) Mandibulo-hyoid-fenestra.
m.hy.	Mandibulo-hyoid.
my.	Myelon.
na.	Nasal capsule.
n.bb.	Nasal barbels.
nc.	Notochord.
n.c.	Nasal cavity.
o.bb.	Oral barbels.
ol.	Olfactory folds.
pa.	Palatine cartilage.
pal.	Palatine mucous membrane.
p.br^{1,2}.	Pharyngo-branchials.
pg.	Pterygoid.
phx.	Pharynx.
p.i.tr.	Hinder intertrabecula.
p.n.c.	Posterior nasal canal.
pr.pa.	Pre-palatine cartilage.
p.tr.	Palato-trabecular.
q.	Quadrate region.
s.l.c.	Supra-lingual cartilage.
s.l.f.	Supra-lingual folds.
s.l.t.	Supra-lingual teeth.
sp.n.	Spinal nerve.
s.o.f.	Suborbital fenestra.
sy.	Symplectic region.
th.v.	Theca vertebralis.
u.l.	Upper lip.
vl.	Velum.

DESCRIPTION OF THE PLATES.

Plate.	Fig.		Number of times magnified.
8	1	Embryo of *Petromyzon planeri*, 7·8 millims. long; side view	33
,,	2	The same; part of upper view.	33
,,	3	The same; part of lower view.	33
,,	4	Larva of *Petromyzon fluviatilis*, 2 inches long (nearly); side view	5
,,	5	The same; part of upper view.	5
,,	6	The same; part of lower view.	5
,,	7	Adult *Myxine glutinosa;* side view	Natural size
,,	8	The same; part of upper view.	Natural size
,,	9	The same; part of lower view.	Natural size
,,	10	Adult *Petromyzon marinus;* lower view of head. . .	Natural size
,,	11	Adult *Petromyzon fluviatilis;* lower view of head . .	2
,,	12	The same; side view of head	2
,,	13	The same; upper view of head	2
,,	14	Adult *Petromyzon planeri;* side view of head . . .	2
,,	15	The same; lower view of head	2
,,	16	The same; upper view of head	2
9	1	Adult *Myxine glutinosa;* dissection of fore part; side view	2½
,,	2	The same dissection (part)	5
,,	3	The same; lower view	5
,,	4	The same; further back; lower view	5
10	1	Adult *Myxine glutinosa;* skull, upper view	5
,,	2	The same, with base exposed	5
,,	3	The same; lower view	5
,,	4	Newly transformed *Petromyzon marinus* (4 inches long); skull, upper view	12½
,,	5	The same; lower view	12½
,,	6	The same; inferior labials; lower view	12½
,,	7	The same; framework of "inferior velum"	15

Plate.	Fig.		Number of times magnified.
11	1–11	Adult *Myxine glutinosa;* first eleven of a series of transversely-vertical sections through cephalic region	10
„	12	The same; fore part of supra-lingual cartilage; upper view	18
12	1–6	Adult *Myxine glutinosa;* twelfth to seventeenth of the series of vertically-transverse sections	10
„	7	The same; lingual and supra-lingual skeleton, with the teeth *in situ;* upper view	5
„	8	The same; supra-lingual framework; upper view	5
13	1–6	Adult *Myxine glutinosa;* eighteenth to twenty-third of the vertically-transverse sections	10
„	7	The same; cephalic region, with lower part of face and throat removed; lower view	2½
„	8	Adult *Bdellostoma Forsteri* (2½ feet long); branchial region; lower view	⅔ natural size
14	1–7	Adult *Myxine glutinosa;* twenty-fourth to thirtieth of the vertically-transverse sections	10
„	8	Adult *Petromyzon fluviatilis;* lower velum, and fore part of branchial region; upper view	7½
„	9	Adult *Petromyzon fluviatilis;* tongue, with anterior and supra-lingual teeth	7½
„	10	The same; vertical section showing supra-lingual and fore part of basi-hyal cartilages	7½
15	1–4	Adult *Myxine glutinosa;* thirty-first to thirty-fourth of the vertically-transverse sections	10
„	5	*Bdellostoma Forsteri* (1½ foot long); from snout to cardiac region; lower view	¾ natural size
„	6	Adult *Myxine glutinosa;* hind part of visceral arches forming framework of "velum;" lower view	9
„	7	The same; fore part of 1st pharyngo-branchial	9
„	8	Adult *Petromyzon fluviatilis;* vertical section of fore part of branchial region to the left of mid line.	4
„	9	The same; another similar section at mid line	4

Plate.	Fig.		Number of times magnified.
16	1	Adult *Bdellostoma Forsteri*, large specimen (2½ feet long); skull, side view of skull	2
,,	2	The same (large specimen); basi-hyobranchial and supra-lingual cartilages ; lower view	1½
,,	3	The same (large specimen); hinder part of lingual muscular mass with 2nd basi-branchial	1½
,,	4	The same (large specimen); supra-lingual apparatus, with teeth	2
,,	5	The same (large specimen), with teeth removed . . .	2
,,	6	*Bdellostoma Forsteri*, small specimen (1½ foot long); vertical section of head and throat	3
,,	7	The same (large specimen); last branchial canal of left side, with "ductus œsophago-cutaneus," and its cartilage	3
17	1	Adult *Bdellostoma Forsteri* (2½ feet long); skull, upper view	2
,,	2	The same, with base of skull exposed	2
,,	3	The same ; lower view	2
,,	4	The same ; outline, with cranial nerves ; upper view .	2

X. *On the Skeleton of the Marsipobranch Fishes.*—Part II. *Petromyzon.*

By WILLIAM KITCHEN PARKER, *F.R.S.*

Received January 10,—Read January 18, 1883.

[PLATES 8, 10, 14, 15, and 18–26.]

IN this Second Part the Marsipobranch type of skeleton will be described in several stages, as far as my materials go; afterwards, I hope to be able to show in a Third Part some of the organs in the act of transformation, the specimens for which I am now expecting.

In the present paper I shall describe :—

A. The skeleton after transformation.
  a. In the adult *Petromyzon fluviatilis.*
  b. In one-third grown *P. marinus.*
  c. In newly metamorphosed *P. marinus.*
  d. In very small (not quite transformed) young of *P. marinus.*
B. The early embryo of *P. planeri;* and
C. The larval form (or *Ammocœte*) of *P. fluviatilis*, ready for transformation.*

These stages give most of the facts we are looking for, but it will be a satisfaction to be able to explain every step in this remarkable metamorphosis.†

The friends to whom I am indebted for materials for the present paper are Professor HUXLEY, F.R.S., FRANCIS DAY, Esq., F.L.S., the late FRANK BUCKLAND, Esq., Professor RAY LANKESTER, F.R.S., the late Professor F. M. BALFOUR, F.R.S. (in conjunction with OSBERT SALVIN, Esq., F.R.S.), F. G. PENROSE, Esq., and Dr. ALBERT GÜNTHER, F.R.S.

---

* Since this paper was read I have received figures of the early embryo of *Callorhynchus* from my son, Prof. T. J. PARKER, who has succeeded in finding an early stage of this important type on the shores of New Zealand. I am now satisfied that the Chimæroids are *not* nearly related to the Petromyzoids.

† The Bibliography has been given in the First Part.

A.—*The skeleton of the Lamprey after transformation.*

I shall at once take up the permanent form of the skeleton, that it may link itself on to that of the Myxinoid form described in the First Part.

a. Dissections of the young (one-third grown) of Petromyzon marinus.

The substance of which the skeleton of the Lamprey is composed is mainly the two kinds of true cartilage, soft and hard. The latter is the densest kind of hyaline cartilage seen in the Vertebrata; greenish, when looked at by reflected light, it is of a clear amber colour when seen in the mounted transparent sections; in the early embryo both kinds are similar, having very little intercellular substance. The *vacuolar* tissue is in the Lamprey confined to the notochord, the sheath of which, as in the Myxinoids, is a strong web of white fibrous tissue.

1. *The post-cephalic part of the axial skeleton.*

Here we have, after metamorphosis, roughly conical patches of hard cartilage (Plate 18, fig. 1; and Plate 22, figs. 7–9, *n.a.*) ascending the sides of the *theca vertebralis,* mounting above it, and having their bases attached to the side of the sheath of the notochord, which maintains its size and its cylindrical form between these paired rudiments, the beginnings of neural arches. This is almost the only part of the post-cephalic region in which anything but fibrous tissue is found as a skeletal structure, for the huge pharnyx is supplied with, and dominated by, a cranial nerve, right and left, the *vagus.* Yet cartilage is continued backwards, as the pharyngeal and pericardial skeleton, as far as the 13th pair of vertebral arches (Plate 18, fig. 1, *ex.br.*, *pcd.c.*, $v.a^{13}$.).

2. The *cranio-facial apparatus—cranium, proper, and ventral or intra-visceral outgrowths* (*rudimentary arches*).

This continuous growth of hard cartilage (mainly) has a much less antero-posterior extent than in the Myxinoids, only part of the hyoid, and none of the *intra-branchial* bars, being developed inside the temporary embryonic head-cavities and persistent aortic arches.

Nevertheless, such evident rudiments of visceral arches as can be found, albeit merely seen as basi-cranial "outgrowths" growing downwards, will be spoken of in familiar terms, the adult Myxinoids, larval Anura, and the larva of *Lepidosteus,* giving us some boldness in the determination of these ventral growths of the head.

For in all these types we have a more or less *continuous* cartilaginous growth of the cranio-facial skeleton; the facial parts being such as are developed inside the remnants of the pleuro-peritoneal space, which for a time remain as the "head-cavities."

The cranial part of the notochord (Plate 18, fig. 4, *nc.*) is twice as long as in the Myxinoids (Plates 9, 10, 16, and 17), for the invested apex can be seen projecting into the small sagittiform pituitary space ("basi-cranial fontanelle," *b.c.f.*), so as to be further forwards than the hind margin of the sub-ocular fenestra (*s.o.f.*). The apex turns upwards (fig. 5, *nc.*), and this part is invested by the hardened parachordals, which end as hard cartilage in front of the hind face of the auditory capsules (fig. 4, *iv.*, *au.*), but send backwards, below, paired spurs up to the point where, in a Tadpole, the occipital condyles would be formed. The cranial notochord becomes invested by cartilage equally above and below (Plate 22, figs. 2–6), and thence, outside, the cartilage thickens and extends right and left, until, reaching the auditory capsules, it, for a considerable extent, underfloors them. Here, however, there is no facial bar growing out from their outer sub-auditory edge as in the Myxinoids (Plates 9, 10, 16, and 17, *au.*, *iv.*, *hm.*). Where the investing mass (parachordals) passes into the trabeculæ (*iv.*, *tr.*), there the basi-cranial cartilage does extend itself into a facial outgrowth—the pedicle (*pd.*).

In front of these outgrowths the basis cranii has an elegant, narrow waist (fig. 4), bounded by the narrow hind part of the trabeculæ (*tr.*), which have a membranous tract right and left of them, and also between them (*s.o.f.*, *b.c.f.*). The middle or "pituitary" space has opened to let out the posterior nasal canal (Plate 23, fig. 1, *p.n.c.*), which passes, widening towards its enlarged *blind* end, under the cranial notochord.

From this point the trabeculæ diverge, and the space left between them is filled in by the hind intertrabecula (Plate 18, fig. 4, and Plate 10, fig. 5, *p.i.tr.*), which is everywhere confluent with them, except where vessels pass through.

The proper basis cranii is finished in front by the confluence of these three bars, and this solid ethmoidal region has a convex outline in the middle, which outline is made sinuous by a retreat of the edge, right and left, where the ethmo-palatine bars have grown on to the trabeculæ (*ep.a.*, *tr.*). This whole floor is concave below, although its middle plate was convex at first, for the pterygo-palatines, like "flying buttresses," drop down, rather suddenly, and thus form an arched, or roof-like structure. A narrow sinuous band of soft cartilage runs along the front of the skull (ethmoidal region, *eth.*), and then hard cartilage breaks out again, in the form of a large shield, which is hollow below, sinuously convex above, notched in front, and at the middle as wide as the skull with its flying buttresses. No one familiar with the skull of Tadpoles can for a moment hesitate to call this the common "trabecular cornu." In the huge Tadpole's skull (*Pseudis*, my first stage, Phil. Trans., 1881, Part I., Plate 2), the cornua are united in their hinder half, but in an older Tadpole (Plate 11, figs. 1–3) they are only separated by a notch in front, sharper, but no larger, than the emargination on the fore-edge of this so-called "posterior dorsal cartilage" of the Lamprey.

The *side* walls of the chondrocranium of the Lamprey are well developed (Plate 18, figs. 1–5), but, as in Tadpoles, and adult Anura also, the optic and trigeminal nerves (II., V.), pass out of considerable *fenestræ*, and not out of mere foramina. The orbito-sphenoidal region (fig. 5, *o.s.*) is wider than the alisphenoidal (*al.s.*), but the latter mounts up into the roof, and the two sides meet round the middle, and fore part of hind, brain (Plate 18, figs. 3, 5, *t.cr.*) The occipital *ring* does not exist, and the hard part of the basi-occipital, as we have seen, is abortively developed.

In front of the posterior sphenoidal "tegmen" there is a large pyriform fontanelle, the broad fore part of which is largely covered by the hinder part of the *double*, mammilliform nasal capsule—(*na.*) an independent structure, as in the Tadpole, larval Urodele, and Elasmobranch; this is composed of soft cartilage.

The facial outgrowths of the Lamprey's skull are confusing, because of their extreme simplicity, and because of the absence in them of the normal segmentation from the basis cranii. Yet the Lamprey is not alone in this peculiar and generalised state of the cranio-facial cartilage; it occurs in so many other Ichthyopsida, especially in the more *archaic* types, that I am strongly induced to look upon it as the retention of an *ancient* condition of the skull of the *Craniata*.

Except in the basal (ventral) region, there is no segmentation, and there the parts are so unlike those of other Fishes that some of these *basi-visceral* cartilages are of doubtful morphology; the question being whether they belong to the *deep* or *superficial* category.

Of parts formed *inside* the "head-cavities" there are only representative *regions* of the 1st and 2nd post-oral arches, and it is evident that the 1st or *maxillo-mandibular* is abortively developed below, and the hyoid abortively developed above; the basal part of the latter, as well as its sides, are clear, but the mandibular region is very doubtfully represented at all.

The only tract that can be said to belong to the proper branchial region (of "intra-branchials") is the hind part of the great lingual cartilage, behind the setting on of the lateral "cornua" of the hyoid arch.

In coming to details, I shall have to refer freely to other work of mine, in other Ichthyopsida, and also to the views written, or expressed to me in discussion, by my esteemed fellow-workers; *from one of the chief of these I can get no more counsel or help.**

---

* I have not felt myself able to stir a step without the help of Professor HUXLEY'S admirable paper already referred to, on the nature of the "Cranio-facial Apparatus of *Petromyzon*" (Jour. of Anat. and Phys., vol. 10, plates 17, 18, pp. 412–429). I say this the more freely because I feel satisfied that the author of that paper will give me credit for having thrown some useful additional light upon the subject, thus necessitating a considerable divergence of opinion between us as to the meaning of some of the parts. The manner in which the late Professor BALFOUR always demanded incontrovertible proof of any view I might be holding at the time of discussion has served to make me work with extreme caution. With regard to one difficulty mentioned by Professor HUXLEY in the paper just referred to (p. 423), as to the distribution of the branches of the 5th nerve, I may mention that in two or three years after its publication

The subocular bar should be compared with that of a Tadpole during transformation, when the hinge of the mandible is below the emerging trigeminal nerve (see Phil. Trans., 1881, Plate 4, figs. 8, 9,) that is when the quadrate condyle has left the front of the head and has retreated to the postorbital region. In the adult Lamprey we have the pedicle (*pd.*) growing forwards as the pterygoid cartilage (*pg.*); these two regions form the hinder, and half the lower, boundary of the subocular fenestra (*s.o.f.*); the rest of the lower boundary is the postpalatine region (*pt.pa.*), and the front boundary the ethmo-palatine (*e.pa.*), from which grows the prepalatine spur (*pr.pa.*).

But there is no quadrate condyle, that is completely suppressed; in the Myxinoids (Plate 9, fig. 2; and Plate 16, fig. 1, *q.*) there is a rudimentary quadrate tract, but without any condyle; in these it is still further back than it would be, if developed, in the Lamprey. The slight elbowing of the subocular bar under the hind margin of the fenestra is the only sign of it in this Fish (Plate 18, fig. 1). That which, for some time, kept me from seeing this matter fairly was a comparison of the Lamprey's skull with that of a Tadpole before transformation; I then mistook the prepalatine spike for a rudimentary quadrate tract. Now if these parts in the Lamprey and the Myxinoids be compared with those of the transforming Tadpoles of the species of *Rana* (*op. cit.*, Plate 4), we shall see that it is the subservience of the free mandible (Meckelian rods) in the Tadpole to the suctorial function—they are mere carriers or supporters of the incomplete "annulus"—that makes the necessity for the forward position of the condyle of the quadrate. Indeed, nothing in morphology is more marvellous than the behaviour of those condyles, which, lying at first in the front of the head, gradually swing themselves round, and, in the Bull-frogs, come to project some distance behind it (*op. cit.*, Plate 8).

Here, in the Lamprey, the perfect *annulus*, or suctorial disk, is functionally free from cranio-facial trammels, and, being so huge, causes the once short, backwardly-placed *lower lip* to project in front of all the other structure; in the Tadpole (see in the huge *Pseudis, op. cit.*, Plate 1) it is almost as forward as in the Lamprey; but in the other kinds it is more under the face.

The forward position of the large quadrate condyles in the Tadpoles of the "Anura Phaneroglossa" masks the prepalatines for a time, turning them *inwards*, as a boundary to the internal nostrils. (See the various figures in my 3rd Memoir "On the Batrachian Skull.")

In *Dactylethra* ("Batrachian Skull," Part II., Plates 56, 57,) the condyle of the quadrate, although well in front of the head, is a small, sessile, selliform condyle on the edge of the enormous suspensorium, and the prepalatine is confluent with the cornu trabeculæ.

But in the larva of the other *Aglossal* Batrachian (*Pipa*, same memoir, Plates 60,

(namely, Nov., 1880), he himself worked out this subject afresh, and found that there was no difficulty, as a true *2nd branch* of the trigeminal *does pass over* the subocular arch. My *later* dissections confirm this important discovery.

61,) that spike (*pr.pa.*) is free, and thus, from the first, has the directly forward position of its counterpart in the Marsipobranchs. Moreover, in the young of *Lepidosteus* (Phil. Trans., 1882, Part II., Plates 30–38, *p.pg.*) we have a prepalatine quite like that of the Myxinoids, and in this case it is the *fore-end* of the subocular bar which is primarily continuous with the basis cranii, but *afterwards* free, whereas it is the *hind part* in the embryo of the Lamprey (Plate 25, fig. 7, *pd.*, *pg.*, *tr.*)*

If we thus determine† that the Lamprey has a subocular arch like that of a transforming Tadpole, *minus* the quadrate region and condyle, we have still the question as to whether the distal (*cornual*) part of the first arch has any existence.

In the first place, it is to me a great satisfaction to find Professor HUXLEY (*op. cit.*, p. 421) saying of the "annular cartilage" that—"although its halves are united dorsally" [it] "would seem to be essentially a post-oral structure;" it certainly is, if it be homologous with the *divided* imperfect "annulus" of the Tadpole.

Now, there is a T-shaped median cartilage, whose transverse part lies directly behind the great labial ring (Plate 10, fig. 6; and Plate 18, figs. 1, 2). After determining (to *my* heart's content) the nature of the "styliform," "cornual," and lingual cartilages, as the hyoid arch, lateral and basal, Professor HUXLEY asks—"What is the *median ventral cartilage* which MÜLLER regarded as the body of the hyoid? The hyoidean arch is complete without it, and has no special connexion with it, the bent up anterior end of the lingual cartilage simply playing over it. I conceive it to be a median ventral element of the mandibular arch, notwithstanding that, in the higher Vertebrates, such an element, though the analogy of the other arches would lead us to expect its presence, is not known to occur. The third division of the trigeminal nerve passes over the expanded anterior end of this cartilage, traverses the ventral half of the annular cartilage, and runs along the anterior edge of the latter to its dorsal extremity" (p. 421). But if we look again at these cartilages in the transforming young of the great Lamprey (Plate 10, fig. 6), we shall see that the paired styloid cartilages of the lower lip are attached by their broader inner ends to the annular cartilage and are curved at their free and outer ends, so as to resemble very closely the form and relations of the small mandibles of the Tadpole (see my 3rd Paper "On the Skull of the Batrachia," Plates 2, 3, 4, 11, 15, 17, 22, 30, and 38).

Now, it occurred to me some time ago that these were the true Meckelian rods, but the late Professor BALFOUR assured me that I had no proof sufficient to sustain this view.

Then as to the median T-shaped cartilage; such a thing as a median mandibular element, well formed, but not segmented off from the Meckelian rods, does exist in "the higher Vertebrates." I have already shown it in the Green Turtle and the

---

* The pharyngo-hyal element or hyomandibular is developed continuously with the skull in *Lepidosteus*, thus throwing light on the second arch of the Myxinoids.

† The difficulty with regard to the relation of the branches of the trigeminal nerve to the subocular bar and fenestra has been dealt with in the First Part (pp. 401–403).

Crocodile (see "Challenger Reports," vol. i., part 5, plate 3, fig. 6, *mk.*; plate 9, fig. 5, *mk.*; plate 10, fig. 6, *mk.*; and plate 11, fig. 2, *mk.*; also Trans. Zool. Soc., 1882, plates 63, figs. 7, 8; 65, figs. 3, 8; 66, fig. 5).

Moreover, I have recently made a large number of preparations of the visceral arches of embryo Mammals—Edentata, Insectivora, Rodentia, &c.,—and in these I find a still more developed basal rudiment to the primary mandibular arch, namely, a large, well-formed terete rod, lying on the symphysis of the "rami," and well marked as a true "basi-mandibular."

Now, considering the morphological feats performed by these Marsipobranchs, notably the two *distinct* "intertrabeculæ" of the Myxinoids, and the marvellous development and sub-division of the basi-hyal, I think it is not a great extravagance on the part of Professor HUXLEY and myself to ask them to show one "sign" more, and give us *three distinct*, rudimentary, distal mandibular elements.

I shall simply call them median and lateral distal mandibular cartilages (*m.d.m.*, *l.d.m.*), and leave their *deep* or *superficial* nature an open question.

Like the annulus they have no existence in the Ammocœte, but this is true, also, of the fore half of the subocular arch, and of all the hyoid arch.

It is evident that the Petromyzine type of skull is a great and important modification (metamorphosis) of the Myxinoid, for the larval Lamprey represents *Myxine*, just as the larval frog represents the Lamprey.

But the enormous development of the lower lip in the Lamprey has affected the jaws, half aborting them, and the hyoid arch, also, in its upper part, and causing its basal part to undergo extreme hypertrophy. The hyoid arch presents fewer difficulties than the maxillo-mandibular, but there are some remarkable modifications of this region, which are, however, greatly elucidated by what we see in the "Anura." It has no "pharyngo-hyal" element; nor has the Tadpole, at first; its distal part, which becomes the "columella auris," does not appear in our Common Frog and Toad until *two* or *three* months after metamorphosis (see my 2nd Paper "On the Batrachian Skull," pp. 622–624)—a fact discovered by Professor HUXLEY. But the *position* of the "epi-hyal" region of the hyoid arch, and its continuity with the back of the pedicle and pterygoid, is only explicable by reference to transforming and transformed "Anura."

The large broad "epi-cerato hyal" of the Tadpole is articulated to a *special* facet by a *special* condyle below the ethmoid in the antorbital region, and it is only after the swinging back, so to speak, of the quadrate region that the *epi-hyal point* is carried under the exit of the facial (*its own*) nerve (see in *Pseudis*, "Batrachian Skull," Part III., Plates 11, 12); this position is a good landmark, and shows that the quadrate of the Lamprey *should have been* post-orbital.

The epi-cerato hyal (Plate 18, fig. 5, *hy.*, *c.hy.*; and Plate 19, figs. 1–3, *e.hy.*) grows out from the back of the pedicle and pterygoid (*pd.*, *pg.*) at a right angle; a projection, the beginning of this part, is seen in the *Ammocœte* (Plate 19, figs. 4, 5, *pd.*). In the adult stage, in some Tree Frogs (*Acris Pickeringii* and *Phyllomedusa bicolor*) (see my 3rd Paper, Plate 30, fig. 2; and Plate 34, fig. 8), the epi-hyal end of the long hyoid "tape" when it has got under the emerging 7th nerve, does not, as usual, unite with the skull, but with the back of the pedicle, behind the part where the pterygoid is given off in front.

Here, as a *secondary* development, we get exactly what we have from the first in the Lamprey; and I could give numerous instances of cases of this kind; homologous parts being *continuous* with some neighbouring cartilage in one type, and becoming *confluent* in another.

The rather thick styliform (epi-cerato hyal) bar of the Lamprey curves gently upwards, as it passes downwards and backwards; it ends below in the *cornual part* or cerato-hyal (Plate 18, figs. 1 2, 5, 6, 7, *c.hy.*). This part is not segmented from the epi-hyal region; but it is quite distinct from the basal bar (*b.hy.*).

The latter bar is strongly clamped by these two horizontal growths, each of which is roughly hatchet-shaped, the blade being turned outwards from the hind part, and the handle growing forwards as a strong styloid process. The thickish blades are convex below, concave above, and a notch is seen between them and their handles; the epi-hyal grows into the top of the outer angle of the blade, which latter part is obliquely perforated in front of its middle.

The facial nerve (Plate 18, figs. 1, 5, VII.) emerges behind the pedicle (*pd.*), and then passes to the inside of the forking cartilage.

The median hyoid bar passes from the circular opening of the mouth to a point half-way between the 1st and 2nd branchial clefts (fig. 1, *b.hy.*); when dissected out it presents the appearance shown in figs. 6–8,—lower, upper, and side views. This rod is not straight, but bent sinuously from side to side, and is upturned both before and behind; it is oval in section, and has an irregular, half soft, keel in the hinder part, where it is clamped by the cerato-hyals. Narrowing into a neck towards the front part, it enlarges at the end into a head, the hind part of which is soft cartilage, and the fore part hard. That hard part is in three pieces, separated by soft synchondrosial tracts. The side pieces form a short trough, and are uncinate blades, united by the convexo-concave lower piece. These parts, which look like the mandibles of a Beetle, have a pair of supra-lingual cartilages over them (Plate 14, fig. 10); and also between the cerato-hyals there is a curious framework to the "lower velum" (Plate 18, fig. 7 *i.v.s.*); these parts I shall describe soon.

3. *On the extra-branchial basket-work.*

In the Myxinoids the only trace of *extra-visceral* cartilage found was in the "ductus œsophago-cutaneus" of *Bdellostoma* (Plate 16, fig. 7); *Petromyzon*, on the contrary, is remarkable in having the largest and most perfect framework of this kind known.

In Tadpoles, behind the three branchial openings, and in front of the first, there are "extra-branchials;" the first and last are pouches, like the bowl of a spoon, the second and third are broad bands. But these have inside them, and growing from large hypo-branchials, four pairs of short and slender cerato-branchials, *inside* the arched branches of the main branchial artery ("Batrachia," Part III., *var. loc.*). Also in Sharks (not in Skates), outside the rays of each branchial septum there is a long band of cartilage, pointed above and pedate below; there are four pairs of these, which are of the same nature as the pouches of the Tadpole and the basket-work of the Lamprey (see Trans. Zool. Soc., vol. x., plate 38, figs. 1, 2, *e.vs.*). In the Shark the typically-jointed intra-branchial arches, with their "rays," dominate; in the Tadpole the extra-branchials; in the Lamprey these latter, alone, exist. The huge development of the seven pairs of branchial pouches in the Lamprey, with their openings—*2nd* to *8th clefts*—carries the fore part of the first pouch away, backwards, from the hind margin of the hyoid; but this is a very slight displacement compared to what we saw (Part I.) in the Myxinoids.

Each main extra-branchial bar is seen to be *behind* the corresponding cleft or aperture (figs. 1, 2, *e.b.a.*$^{1-7}$, *ex.br.*$^{1-7}$); but in the adult, there is an additional bar, in front, belonging to the hyoid region, and another behind, enclosing the heart and its bag (*ex.hy.*, *pcd.c.*)* These *nine* pairs of main bars are all united below (fig. 2) into one complex cartilaginous "crate." The cartilage is of the soft kind. Above, on each side, the seven main bars run into each other, being united by a continuous growth, attached by fibrous tissue to the sheath of the notochord. Opposite the apertures each bar bends inwards, and, above and below, the inbent part gives off a crooked bar, both over and under the apertures. These cross bars join the next in front at a considerable distance from the aperture, each being strongly elbowed, and each giving off a snag, the one upwards and the other downwards. But the *cervicorn* character of these united bars is increased still further by the development of two snags in front and one behind, on each main bar, both above and below the cross bars. Then, both above and below, a common headland of cartilage unites the whole together. Nor is this all, for the lower marginal band (Plate 18, fig. 2), uniting the main bars below, bends towards the corresponding part of the other side, and coalesces with it at its convexity. This being done, again and again, there is left a row of small oval fenestræ between the junctions—*six* in all. But the hyoid part of the basket-work, the "extra-hyal" (*ex.hy.*) did not exist till after the metamorphosis (see Plate 25, fig. 8, basket work of *Ammocœte*) and the cross bars of the 1st extra-branchial (*ex.-br*^{1}.) form a loop independently of the extra-hyal. This loop, however, sends down, now, an elbowed band, which runs into the extra-hyal below its middle. The extra-hyal helps to form the grooved and perforated *quasi-sternum* on the lower face of this great respiratory pharynx (fig. 2, *ex.hy.*) and above its junction with the 1st extra-branchial (*ex.br*^{1}.) runs upwards and forwards, and is united with its own arch (epi-cerato hyal, *e.hy.*, *c.hy.*) over its junction with the pterygo-palatine (fig. 1). Just at its shoulder, below the emerging facial nerve (VII.), the extra-hyal sends upwards a free snag. The last extra-branchial (*ex.br*^{7}.) sends off no cervicorn processes, except from the transverse bars. It is shorter also than the rest. Behind, it joins the *extra-pericardial* (*pcd.c.*) by *three* bands, the lower being the broader (fig. 2), and each of the *two* fenestræ thus formed is made into a U-shaped space by a snag from the extra-pericardial, which also sends forwards, above them, a larger free dentate snag; the rest of the pouch is thin, roundly notched, and ends above in another similar process. Below (fig. 2), instead of a small oval fenestra, the 7th extra-branchials help the double extra-pericardial to form a large fenestra, which becomes elegantly trilobate through the growth of a right and left snag from behind. From that fenestra, up to the pair of upper processes, right and left, the two extra-pericardials are completely united together, and form a *bowl*, whose cavity is pitched forwards and a little upwards. I trust that the reader, with this description of the figures here given, will see what the writer sees, and that, seeing, he will agree with him that nothing more remarkable, and nothing more exquisite, has been revealed by the labour of Anatomists.

---

* The Tadpole has no gill belonging to either the first or the second arch; therefore its three gill-slits answer to the 2nd, 3rd, and 4th gill openings of the Lamprey, whose 1st gill opening is the 2nd cleft.

4. *Subsidiary cartilages in the mouth and between the mouth and pharynx.*

a. The supra-lingual cartilages.

Over and between the curious *quasi-mandibles* that grow upwards from the head of the basi-hyal (Plate 18, figs. 6–8, *b.hy.*) there is a thick pyriform cushion, right and left, with its base looking backwards. Between these two cushions, in the margin of an elliptical *supra-lingual* valley, there is a pair of rows of small, yellow, pointed, lanceolate teeth, looking inwards and backwards, a dozen or more in each row (Plate 14, fig. 9). There is a groove along the mid-line, between them, and behind this the dorsum of the tongue has crescentic cross ridges. Across the arched, broad end of the tongue there is a row of *cyclodont*, beaded, horny teeth, fifteen in all, lessening outwards, and with the middle tooth much the larger. These show themselves inside the *annulus*, on the floor of the small oral opening (Plate 8, figs. 10, 11), and are a very important part of this suctorial apparatus. But these terminal teeth of the tongue, and the radiating teeth of the annular disk, have no counterparts in the Myxinoids (Plate 8, figs. 7–9). The two small rows of sharp, supra-lingual teeth have, however, very notable counterparts, in the double rows of large teeth, in that lower group (see Plate 12, fig. 7; and Plate 16, fig. 4). The large complex supra-lingual cartilage of the Myxinoids is represented in the Lamprey by a small cartilaginous plate (Plate 14, fig. 10, *s.l.c.*), which is exposed by section in the cushion above the ascending lobes of the great basi-hyal (*b.hy.*).

b. The skeleton of the fimbriated valve between the mouth and pharynx.

This peculiar structure, formed during metamorphosis, is figured, as seen in a vertical section of the adult *P. fluviatilis* (Plate 23, fig. 1); from above, *in situ*, in a head cut through horizontally (Plate 23, fig. 2); and as removed from most of its surroundings and seen from above (Plate 14, fig. 8).

The skeleton of this valve is shown in the upper view of the basi-hyal (Plate 18, fig. 7, and in Plate 10, fig. 7), and sections of it will be described anon. This part is a fringed median projection, uniting the right and left *vela* (*vl.*), parts that are found in the newly-hatched embryo, dividing the "stomodæum" from the "archenteron" (Balfour, 'Comp. Emb.,' vol. ii., p. 74, fig. 42, *v.*). I have given a diagrammatic figure of the velum in the *Ammocœte* (Plate 25, fig. 10, *vl.*). For a description of these parts the reader is referred to Professor Huxley's paper ("Cranio-facial Apparatus of *Petromyzon*," p. 420). This curious little frame is composed mainly of two *crura* of hard cartilage, united in front by a band of soft cartilage, which sends out three pairs of filaments, and an odd one in the mid-line. These are all sinuous or *f*-shaped; the two outer threads pass across and are attached to the cerato-hyals (*c.hy.*), in front of their junction with the epi-hyals (*e.hy.*); these latter are seen as cut across in the figure.

The inner of the paired threads is the longest, right and left; the others are nearly of the same length.

The hard crura are bent out, like *knees*, and these are pedate behind, with a *heel* of soft cartilage.

5. *The labial cartilages.*

The upper lip, which was a *hood* in the embryo and larva (Plate 8, figs. 1–6), overlapping and far outreaching the short, transverse lower lip, has grown very much, but not in the same degree as the lower lip (Plate 8, figs. 10–16; Plate 18, figs. 1, 2, 3; and Plate 23, fig. 1).

The upper lip has acquired a skeleton, such as we find in all the Tadpoles of the "Phaneroglossal Anura." There are five *upper labials* in this type, and the median is a shield-shaped piece, hollow below, convex above, and overlapped by the cornu trabeculæ (*u.l*^{1}., *c.tr.*); these two parts are the so-called "anterior" and "posterior dorsal cartilages." Under the lower edge of the great median upper labial, right and left, there is a small, bent, bluntish style, the "antero-lateral upper labial" (*u.l*^{2}.). Behind the large piece, right and left, there is a reniform plate of cartilage, much larger than the styloid piece, which, lying obliquely, helps to fill up the space between the two dorsal cartilages and the prepalatine; this is the "postero-lateral upper labial" (*u.l*^{3}.).

In the larva of the "Anura" (see Phil. Trans., 1881, Part I., *var. loc.*) these cartilages never *quite* agree with those of the Lamprey, although they are manifestly homologous. There may be *one*, *two*, or *four*, and they are evanescent in those types, becoming absorbed during metamorphosis, whilst *two new pairs* appear, homologous with the "adrostral cartilages" and "nasal valves" of the *Elasmobranchs.*

I have already described the cartilages that are attached to the *great ring*, doubting whether they belong to the *superficial* or the *deep* category.

There remains, now, the great *annular* cartilage to be described (Plate 18, figs. 1–2, $l.l^1$.), and the lesser pieces in the disk ($l.l^{2-4}$.). There can be no difficulty in identifying this huge, single, complete ring with the lesser, double, incomplete ring of the Tadpole, nor in determining that they are both distal superficial cartilages of the post-oral or mandibular region. I have traced the development and decadence of this suctorial structure through all its stages, *up* and *down,* in the Anura ("Skull of Batrachia," Parts I.–III.), but in this type I find no traces of it in the largest *Ammocœte* of *P. planeri* and *P. fluviatilis.* But in a very minute young of *P. marinus*, 4 inches long, (Plate 10, fig. 6, $l.l^1$.)* with the cranial elements still distinct, the chondrification is equally perfect all round, and the thickness of the ring equal. At that stage, if it had been composed of two pieces, even for *a day or two,* some signs of division would have been apparent. The actual form in the larger young (one-third grown) of the same species (Plate 18, figs. 1, 2, $l.l.^1$) is a semi-ellipse, with rounded corners at the truncated part; the narrow end is in front.

It has a thick lower edge (fig. 2) and thence is scooped upwards; the fore part (fig. 1) is much higher than the hinder; the narrow end projects much less in front of the large upper labial than *it* does beyond the cornu trabeculæ (Plate 18, figs. 1, 3, $l.l^1$., $u.l^1$., *c.tr.*). In the side view (Plate 18, fig. 1) the larger teeth, round the opening of the circular mouth, are shown *in situ;* in the dissected skull in the under view (fig. 2), the head of the tongue (lingual or basi-hyal cartilage) is seen with its teeth in the hinder part of the opening. Also in the undissected head, when seen from below (Plate 8, fig. 10), the same part is seen as a squarish mass, largely occluding the aperture; the teeth of the disk are strong and crowded behind the aperture.

In the thick edge of the disk, right and left, there are three small, hard cartilages of an irregularly oval shape (Plate 18, fig. 1, $l.l^{2-4}$.).

6. *The sense-capsules.*

The eye-balls, which are very small and obscure in the *Ammocœte* (Plate 8, figs. 4, 5) are large in the adult (figs. 11–13); in the middle species (*P. fluviatilis*) the relative size of this organ will be shown in the sections. Unlike the eye-ball of Fishes, generally, the *sclerotic*, even in *P. fluviatilis* where the eye-ball is relatively largest, is not cartilaginous but fibrous, merely, as in the Mammalia.

The auditory capsules (Plate 18, figs. 1, 3, 4, *au.*) are very similar to those of the Myxinoids (Plates 9, 10, 16, and 17), being strong, hard, oval capsules, retaining the simple form found in the newly-hatched embryo of the Anura. For in these types the anterior and posterior semicircular canals are short, wide tubes, and the horizontal canal is arrested. The meatus auditorus internus (Plate 18, fig. 5, VIII.) is scarcely larger than the optic fenestra (II.), so that, for a Fish, the capsule is very perfect inside; the space for the entrance of the auditory nerve is much more vertical than in the Myxinoids (Plates 10 and 17). The long axis of these elliptical boxes is accurately parallel with the axis of the skull; above, they stand out well from the skull, but below we see a bridge of cartilage, derived from the parachordal (*iv.*), thrown across the interspace between the capsule and the cranial floor. This scooped thin edge of the parachordal, which has become confluent with the capsule, is very distinct, for a time, in Tadpoles ("Batrachian Skull," Part III., *var. loc.*); it is continuous with the pedicle (*pd.*) in front, and in the Myxinoids (Plates 9, 10, 16, and 17) with the uppermost part of the hyoid arch.

---

* In that figure the distal mandibulars are lettered $l.l^2$., $l.l^3$.

That the *nasal capsule* (Plate 18, figs. 1, 3, 5, *na.*) is essentially double, like the trabecular cornu (*c.tr.*) is evident; it is a very exact likeness of the dilated crop of a Pigeon; its halves are a little less than the auditory capsules; they are composed of *soft* cartilage. Behind the aperture (*e.n.*) there is an emargination, followed by a widish, shallow groove; behind, the median cartilage is somewhat produced as a lobe. The cartilage runs three-fourths of the way round (Plate 21, figs. 3–5) up to the posterior nasal canal, and only forms a perfect floor behind; the aperture (*e.n.*) is membranous. These things will be best explained by the transverse sections (Plate 21). The roof is pierced by vessels, near the middle, at its hinder third (Plate 18, fig. 3, *na.*); in that figure the olfactory nerves (I.) must be supposed to be seen *through* the fontanelle (*fo.*).

Cranio-facial skeleton of newly-metamorphosed young of Petromyzon marinus.
(5 *inches long*).

These were about half the length of the specimen whose skeleton has just been described; and, in development, an intermediate one between that stage and the one next to be described.

Compared with the larger specimens, we see that the cranial notochord is longer, being half as long as the cranium proper, so that the *para-* and *pro*-chordal regions are equal in length. The notochord (Plate 19, figs. 1–3, *nc.*) projects somewhat into the oval pituitary space (*b.c.f.*), which is twice as large as in the larger specimens. The inner edge of the parachordals is soft both above and below; the two are united for a short space below. The outer edges, confluent with the auditory capsules (*au.*) are of less extent, there being a considerable notch fore and aft under the outgoing trigeminal, facial, and vagus nerves (V., VII., X.). The hard cartilage is continued back, as far as the hinder outline of the auditory capsules, and is then replaced by narrowed bands of the soft kind, further than in the last stage. Behind, the *pro*-chordals (*tr.*) are narrower than the *para*-chordals (*iv.*), but they broaden out forwards; their larval form is traceable in the upper view (compare Plate 19, figs.

1 and 5, *tr.*), for the basi-cranial fontanelle (*b.c.f.*) is bounded by a thick cartilage, which thins out in the orbito-sphenoidal and ethmoidal regions (*eth.*, *o.s.*)—*post-transformation* structures. The floor in front of the basi-cranial fontanelle is due to the hind intertrabecula (*p.i.tr.*). A large round notch separates the ethmoidal and orbito-sphenoidal regions; the ethmoidal plate in front of this notch and of the thick-ribbed primary trabeculæ, is a two-winged structure, pointed in the middle, gently concave right and left, convex above, and concave below. It thickens beneath at its fore margin. There is a curious rudiment of the wall and roof, right and left; the base of the orbito-sphenoidal wall (*o.s.*) is only half the breadth of the *optic fenestra* (fig. 3, II.). The top of the wall is spiked in front, and then notched and sinuous; it bends inwards over the optic fenestra, and is thick above. The appearance, from above (Plate 19, fig. 1) of these partial walls, is like that of the pterygo-palatines (*pg.*, *pa.*) outside, but much smaller. The optic fenestra is kidney-shaped, the *hilus* being above, and the nerve (II.) passes out at the hinder third. The base of the alisphenoidal band (fig. 3, *al.s.*) is only half as large as the orbito-sphenoidal (*o.s.*), and a large uncinate foramen for the 5th and 7th nerve (V., VII.) intervenes between that band and the auditory capsule. Then the cartilage mounts over the skull cavity beyond the middle of the auditory capsules, forming a leafy blade, that grows, by its fore corner, towards its fellow of the other side, but does not meet it by a considerable space. The hind corner lies on the capsule, furthest from the mid-line, and a fenestra is seen between the *foramen ovale* (fig. 3, V.), the ear capsule, and the hind margin of the rudimentary "tegmen" (*t.cr.*).

The front outgrowth of the cranium—the great leafy hollow cornu trabeculæ (*c.tr.*)—is more than two-thirds the size of the rest of the cranio-facial structure; it is emarginate at both ends, and at its hinder part it is joined on to the ethmoid (*eth.*) by a very definite tract of soft cartilage; at that part it is slightly grooved, above.

At the junction of the *pro-* and *para*-chordals (*tr.*, *iv.*), and also at the outer margin of the ethmoid, a stout band of cartilage passes out; these are united outside, as a sort of "flying buttress," which sends forwards a free snag, and downwards, at a somewhat greater distance from the skull, a band of cartilage, equal to the size of the root; this is drawn as cut across at a little distance from its origin. The hind root is the pedicle (*pd.*); the front root the ethmo-palatine (*e pa.*); the spur is the pre-palatine (*pr.pa.*); the bar cut across is the epi-hyal (*e.hy*), with no distinct inter-hyal tract; and the main outer wing is the post-palatine (*pt.pa.*), passing into the pterygoid (*pg.*). There is the merest convexity at the junction of the two last-mentioned regions, where the *quadrate region* and *condyle* should be.

I have not figured the nasal capsule in this stage; the auditory (*au.*) is large, sub-reniform, and has a large pyriform *meatus internus* (fig. 3, VIII.), with the fundus below.

Cranio-facial skeleton of nearly metamorphosed young of Petromyzon marinus. (*4 inches long.*)

This stage is still more instructive than the last, as the metamorphic state was not over,—the *Petromyzine* skull was still in formation, and was caught in what may be called a *Myxinoid stage* (Plate 10, figs. 4, 5). Yet the suctorial (labial) cartilages were perfect (fig. 6); these have already been described, and the skeleton of the *intervelar shelf* (fig. 7), which was almost as much developed as that of the larger individuals of the same species (see Plate 18, fig. 7).

If the reader will compare this minute chondrocranium with that of *Myxine* (Plate 10, figs. 1–3), with the *larva* (Plate 19, figs. 4, 5), and with that of the transforming Tadpole of the East Indian Bull Frog (Phil. Trans., 1881, Part I, Plate 4, figs. 8, 9), he will not fail to see its true morphological signification—both *those* skulls are twice the size of *this*, yet this belongs to the largest species of Lamprey.*

Another skull which comes near to, and throws light upon this, is that of the *transforming* Tadpole of *Pseudis* ("Batrachian Skull," Part III., Plates 11, 12). Here the primary basal bands—*para-* and *pro*-chordal (Plate 10, figs. 4, 5, *iv.*, *tr.*), have their *larval* outline (see Plate 19, figs. 4, 5) perfectly distinguishable throughout. The chondrification creeps backwards, as in the early Tadpole's skull, for here the hard cartilage is seen to end some distance in front of the hind margin of the ear-capsules (*au.*); the soft cartilage runs back along the spinal notochord for some distance. The sub-auditory wings of the parachordals are less than in the last stage and are very thin; the space under the gasserian ganglion between the pedicle (*pd.*) and the capsule (*au.*) is much larger and more open than in the larger young (Plate 19, figs. 1–3). The basi-cranial fontanelle (*b.c.f.*) is now pointed in front—*sagittate;* and narrower than it will be in a few weeks.

The trabeculæ (*tr.*) in front of the pedicle (*pd.*) become half the size of the parachordals, and then widen out, both in thickness and distance, to form the *Ammocœtine loop.* The depth of the floor is made by the thickness of the trabeculæ and its own concavity; and the bands are oval in section, the long axis of the oval looking upwards and inwards (see Plate 26, figs. 7–9, *tr.*). The interspace of the *loop* is accurately fitted with a cartilage, like the bowl of a spoon, but with two points, behind, instead of a handle; this bifurcation gives the lanceolate form to the basi-cranial fontanelle (*b.c.f.*).

This thin shell-like median element is the "posterior intertrabecula" (*p.i.tr.*); although only transitorily distinct, and composed of hard cartilage, it is the true counterpart of the very distinct ladle-shaped, soft cartilage, seen in the adult Myxinoids (same Plate, figs. 2, 3, *p.i.tr.*). This element is more distinct, as a rule, in the

---

* I shall describe the larval skull last (Plate 19, figs. 4 and 5); yet that simple platform of a chondrocranium must be kept in sight, if the more advanced condition is to be understood. I have thought it better to take the metamorphosed skull first, as Anatomists are most familiar with it.

"Amniota" than in the "Anamniota;" especially, as I have noticed, in the Turtle and Crocodile; its outline, as distinct from that of the paired trabeculæ, can be traced in embryo Mammals, especially *Marsupials.* Here, its presence, *even for a few days,* as a distinct element, is very instructive, showing that, in some respects, the Petromyzoids lie between the Myxinoids and the Anura. *In some respects;*—but the larval Anura (see "Batrachian Skull," Part III., Plate 30, figs. 10, 11, *p.e.*) show very clearly the independence of the "anterior intertrabecula," which has no existence in *Petromyzon,* but is so remarkable in the Myxinoids (same Plate, figs. 2, 3, *a.i.tr.*). In those forms it supports the *prenasal proboscis;* in the larval Anura, with symmetrical nasal capsules, it forms the wall of partition between them, whilst the short narial passages acquire, each, a crescentic valvular cartilage, representative of the series of imperfect rings in the Myxinoids.*

In spite of the difference of form and of the character of its tissue (*hard* instead of *soft* cartilage), and of its very temporary separateness, no one can fail to see its morphological identity with that of the Myxinoids (Plate 10, figs. 2, 3, and figs. 4, 5, *p.i.tr.*).†

This small, scarcely transformed skull of the Lamprey shows exactly what has been built upon the *Ammocœtine* foundations (see Plate 19, figs. 4, 5; and Plate 10, figs. 4, 5). Outside the newly floored fore part of the skull, a flange or wing of cartilage has been added, which widens from behind forwards, until it shoots out right and left, as the ethmo-palatine (*e.pa.*) This flange runs round the looped trabeculæ in front, and thus the ethmo-palatines have an elegant, narrow, arched commissure running concentrically round the front of the early trabecular commissure.

This peculiar structure explains what was to me very anomalous in the transforming skull of the huge Tadpole of *Pseudis* ("Batrachian Skull," Part III., Plates 11, 12) where these bands are seen to pass into each other, under the ethmoidal region of the skull, and to have a distinct margin, marking the commissure off from the basis cranii, behind the transverse band. Here, however, there has been *coalescence of the basi-cranial flange with the ethmo-palatines,* for in the *Ammocœte* (Plate 12, figs. 4, 5), the subocular band of cartilage is only developed in its hinder third; in the Tadpole these parts are primarily continuous.

The *secondary* character of the cornu trabeculæ (*c.tr.*), is shown in this little skull, and also its essentially double nature. It is, now, separated from the ethmoidal flange by a narrow tract of soft cartilage, which, however, expands at the median line, thus giving *two roots,* as it were, to this large leafy tract. The fore edge is ragged, and there are points of cartilage, where broad lobes will be in a week or two (see also Plate 19, figs. 1, 2, *c.tr.*). At this stage the "flying buttress" is much more like that of the late Tadpole of the Bull Frog (*op. cit.*, Plate 4, figs. 8, 9), than in the next stage (Plate 19, figs. 1, 2), for the whole framework is more outspread, and the prepalatine (*pr.pa.*) points forwards, leafy and flat.

---

* In retaining the old *human-anatomy* names, for descriptive purposes, in special districts or regions, the morphologist is saddled with a double nomenclature. For as our conception of the development of the parts becomes more and more clear, there must of necessity arise a number of *general terms,* each of which may include several special descriptive terms. Thus, the general morphological term "intertrabecula," which I have added to Rathke's term "trabeculæ," includes the perpendicular ethmoid, and the septum nasi; the prenasal rostrum; and the median part of the anterior and posterior sphenoidal regions.

† It is due to the late Professor F. M. Balfour to state that the determination of the cranial nature of this peculiar median cartilage of the Myxinoid skull is due to him, and that this was seen independently of the peculiarly conclusive instance of it in the young Lamprey. It seemed to me, for a while, to be a *median palatine* cartilage, forming a floor to the "posterior nasal canal," and putting this view forward to him, as a suggestion, his immediate answer was, "No; it is your intertrabecula."

The subocular fenestra (*s.o.f.*) is made reniform by the basi-cranial flange; its more arched outer boundary is made by the postpalatine (*pt.pa.*) passing into the pterygoid (*pg.*), which runs upwards into the pedicle (*pd.*), and downwards into the epi-hyal (*e.hy.*), without a trace of the quadrate lobe and condyle, and without a sign of segmentation. If we compare these stages of the skull of *P. marinus*, one-third grown (Plate 18); 5 inches long (Plate 19, figs. 1–3); 4 inches long (Plate 10, figs. 4, 5), we shall see that the auditory capsules are relatively larger the younger the specimen. Also that they are short-oval in the youngest, then reniform, and then short-oval again. At first the semicircular canals make no difference in the outer form; then the two wide tubes bulge the capsule out; and this is lost, afterwards, by the thickening of the walls of the capsule. The meatus internus (Plate 18, fig. 5, VIII.), is pyriform and smallish in the largest of the three, then relatively large in the next (Plate 19, fig. 3), and in the smallest (Plate 10, fig. 4), it is a large, gaping space. In making these comparisons we have to keep the particular *species* in view, for in *P. fluviatilis*, the capsules of the *Ammocœte* (Plate 19, figs. 4, 5) are already reniform.

My work has been done according to what was possible with the materials at hand, first one species and then another; the reader must make the proper *specific equation.*

Solid sections of the head and branchial region of the adult Petromyzon fluviatilis.

A.—*Vertical sections.*

The various sectional views have purposely been made bald and diagrammatic, for the skeletal parts are very complex, and their relations to the surrounding parts very manifold and confusing; an exhaustive memoir on the anatomy of this type would have to be tenfold the bulk of this selected piece of work.

In the large vertical section (Plate 23, fig. 1) the segmental muscles and their deciduous septa are seen to have mounted up and overlapped the cranium as far as the external nasal opening (*e.n.*); below, the ventral muscular bands are merely indicated in the figure. The myelon and cerebrum (*my.*,* C^{1-8}.) are seen enclosed in their fibrous sheath (*theca vertebralis* and *dura mater*), and below them is the large notochord (*nc.*) enclosed in its thick fibrous sheath; it is cut through along its axial fissure (Plate 23, figs. 4–7, *nc.*), and its apex reaches to the part where the posterior nasal canal (*p.n.c.*) emerges from the skull cavity.

---

* The line from *my.* is too low in this figure.

Below the notochord the special, narrow, long *food-pharynx* (*phx.*), is laid open; near the head this passage bends downwards *under* the nasal canal, and *over* the frimbriated shelf (see fig. 2, *i.v.s.*) the "intervelar shelf," or fringed floor. Then, enclosed in connective tissue, we see the special branchial diverticulum of the pharynx, the *branchial bronchus*, perforated by seven erect, oval, valvular apertures or clefts, each of which opens into a branchial pouch (see fig. 2, *i.b.a'.*). Below this large perforated tube, a *cul de sac*, another similar but smaller perforated tube, is seen; this is the great branchial artery (or *aorta*) (*br.a.*), giving off its secondary branchial arteries to the pouches. Below these parts we see muscles and inter-muscular septa, the structure of which does not concern us now. In front of the structure just described, where the mucous membrane is lined with cells derived from the *hypoblast*, we see the large oral or buccal involution, the epithelium of which is epiblastic. This is divided into two regions, the *labial*, or region of the *disk*, and the proper mouth cavity (*m.*), expanding into a *buccal* space right and left of the vela and intervelar valve. The first space is a low, highly ornate dome, pierced above to form the proper oral opening (see Plate 8, fig. 11), which is reduced to an arched fissure by the broad dentate end of the tongue. The oral cavity is very extensive, but it is partly taken up in front by a peculiar shelf, containing the great upper labial (*u.l*^{1}.), and, behind, its height is lessened by the pouched end of the posterior nasal canal (*p.n.c.*). That canal is seen to emerge from the cranial cavity in front of the notochord, and then to end between the notochord and the depressed part of the food-pharynx (*phx.*); it has a right and left diverticulum near its end. Narrowing in its intercranial tract, we see it widen again, under and in front of the nasal sac (*na.*), where it opens with the nasal opening (*e.n.*); its general form, in outline, is bracket-shaped.

The skeletal parts displayed in this section are as follows:—

The tegmen cranii (*t.cr.*) over the junction of the mid and hind brain (C^2., C^3.); the nasal roof (*na.*) and a sigmoid tract under and in front of the skull; this is intertrabecula behind, ethmoid in the middle, and cornutrabeculæ (*c.tr.*) in front; the investing mass shows a little where it is cut through, over and under the apex of the notochord.

In the base of the mouth and throat the large basi-hyal (*b.hy.*) is halved, its soft and then its hard part, in front, is shown; it reaches behind to the second branchial opening. The thickest part of the annular cartilage (*l.l*^{1}.) is above, the narrowest is below, the thin arched cartilage above and behind the upper section is the great median upper labial (*u.l*^{1}.). forming the skeleton of the shelf under the cornu trabeculæ. Below the basi-hyal, the median distal mandibular (*m.d.m.*), is seen close inside the proper chin, behind the fissure between the chin and the great sucking disk. The small points of cartilage cut through where the two systems of extra-branchials conjugate, below, were only figured in three places, in front (fig. 1, *ex.br.*).

Two *partial* vertical sections are figured, one (Plate 15, fig. 9) near the mid line, the other (fig. 8) more to the side. In the one nearest the middle (fig. 9) the fore part of the notochord is shown bent upwards, the cephalic part being enclosed in hard cartilage. The posterior nasal canal (*p.n.c.*) ends beneath its front spinal region; that pouch is seen to have a valvular fold inside it.

Under the pouched end of this canal, the buccal cavity is partly shown, with a small tract of the facial cartilage between it and the branchial canal; and another small point of cartilage is caught in this region, namely, part of the skeleton of the "intervelar shelf." The fore part of the branchial canal (*br.c.*) is exposed beneath the valvular end of the posterior nasal canal, and in it two oval internal branchial passages, and a *small valvular pouch* in front, at a lesser distance from the first opening than from the second. These are, in truth, the first three clefts, but the foremost, or hyomandibular opening (cl^1.), does not pass through the wall of the head, and has developed very little since it first appeared. Evidently, *it never quite closed up, or, if it did, it opened again* during metamorphosis. In the more lateral section (Plate 15, fig. 8) the investing mass shows more in the cranial end of the notochord (*nc.*, *iv.*), and beyond it, in front of the posterior nasal canal (*p.n.c.*), the basis cranii is seen. Here we have the same openings—the first *closed*, and the two next *open* clefts, and in front of these the folds of the velum (*vl.*), and part of the frimbriated "intervelar shelf." Between the lateral and sub-lateral filaments of the shelf there is seen a deep pyriform recess, this is the *lateral buccal pouch* (to the right of *b.p.*), a diverticulum of the oral mucous membrane in front of the pharynx. It will be seen that the food-pharynx is not figured in these two sections, they were made beyond or outside the wall of this narrow tube (see Plate 23, figs. 1 and 4, *phx.*). The main crus of the one side of the *intervelar* skeleton is cut through (fig. 8, *vl.*).

B.—*Horizontal sections.*

These sections help us to understand this peculiar type of cranio-facial skeleton. In the higher of the two (Plate 23, fig. 3) we see the eye-balls (*e.*) cut through their middle, and also the auditory capsules (*au.*) in which the multilocular membranous labyrinth of each side is laid open. In front, the ethmoid (*eth.*) is cut across in its most solid part, and behind it, we see the outer nasal opening (*e.n.*) cut down close to the capsule (*ol.*), and in front of the ethmoid, part of the 2nd lateral labials are seen. Behind the nasal capsule we see the fore brain (C^1.) and the cranial side walls (*o.s.*), which are sinuous and out-turned at each end, with the orbital muscles and eye-ball (*e.*) attached. Part of the pedicle is seen confluent with the auditory capsule (*au.*); the latter is open on the inner side for the entrance of the auditory nerve. The first pair of neural arches of the spine ($n.a.^1$) are cut across, some of the notochord, and part of the first pair of branchial pouches.

In the next section, taken at a lower plane (Plate 16, fig. 2) the lower part of the eye-balls is shown, and the oral cavity is exposed with the intervelar fringed shelf (*i.v.s.*), the two-leaved "vela (*vl.*)," and the fore part of the branchial bronchus (*br.c.*) The first (arrested) cleft, and the first proper branchial opening are hidden under the folds of the "velum," but the 2nd and 3rd branchial apertures are shown clearly, and also the cavities of the three foremost pairs of pouches (*br.p.*) Both the cerato-hyal (*c.hy.*) and the stem of the intervelar skeleton (*i.v.s.*) are cut across. In front, the annulus ($l.l^1.$) is cut across, right and left, and also the labial distal mandibular cartilages (*l.d.m.*). Then close to the floor of the mouth the highest part of the basi-hyal (*b.hy.*) is caught; outside it, the lower edge of each 2nd lateral upper labial ($u.l^3.$); and close under the eye-ball the pterygo-palatine bar (*pp.g.*). [In this figure for $i.b.a^1$. read $i.b.a^2$., and for $br.p^1$. read $br.p^2$.]

Vertically-transverse sections of the head of the adult Petromyzon fluviatilis.

In one rather small specimen nearly six scores of thin sections were made, stained with *eosin*, and mounted as transparent objects, in Canada balsam; of these rather more than one in four were drawn (Plates 20–22; and Plate 23, fig. 4). These reached from the sucking disk to the 2nd branchial pouch. Other sections were made by hand (solid) from the hind part of the branchial region of a very large specimen, which had been solidified in a solution of chromic acid (Plate 23, figs. 5–7). In these latter sections the muscular masses are more accurately shown than in the thin specimens that have been interpenetrated with *oils* and *resin*. These parts, however, are drawn in the figures merely to indicate the relation of the skeletal parts; it does not enter into my plan to describe them. As they appear in the figures they will be easily understood by the Anatomist. It is utterly impossible for any figures to give an adequate idea of the beauty of the transparent sections.*

1*st Section* (Plate 20, fig. 1).—This section is through the fore part of the suctorial disk,† and this, and the next, are in front of the trabecular cornu. The median upper labial ($u.l^1.$) is cut across in its narrower fore part, and beneath it the annular labial—the azygous element of the lower series ($l.l^1.$)—is seen cut across right and left of the high arched space shown by section of the great disk. This is near the front part of the annular cartilage; it is highest and thinnest at this part, and is bent upon itself below the middle. Hence in the outer view (Plate 18, fig. 1, $l.l^1.$) the upper part of the side seems to be bevelled. Below this, at a small distance, there is a somewhat lesser section of cartilage, which is not curved; this has suctorial teeth on its inside, and it lies opposite the middle of the large labial muscular mass outside the cartilage (*s.d.*), the section of which is crescentic; the annular cartilage gives attachment to these fibres, above; its upper edge, only, is free. The lower cartilage is called by SCHNEIDER (see his plate 8, fig. 1, *Cd.*) "Cartilago-dentalis" ("Knorpel für die seitlichen Zähne"). I have not, elsewhere, seen this cartilage noticed, and my sections created for a time a difficulty: *dissection* of the suctorial disk, both of the young *P. marinus* and of the adult *P. fluviatilis*, gave the explanation. There is not merely *one lateral lower labial* on each side, but *three* (Plate 18, fig. 1, $l.l^{24}$.); they are small, irregularly oval patches of hard cartilage, lying in a profusion of large-celled simple cartilage, quite like that seen in the larva of *Dactylethra* and intermediate between the "vacuolar tissue" of the notochord (and of the huge basi-branchial bar of the Myxinoids), and the ordinary soft cartilage of Marsipobranchs generally. This large-celled simple cartilage fills the cavities of the horny teeth, and is, indeed, the kind of pithy connective tissue which goes to fill the interspaces of the higher kinds of tissue in this large spongy disk.*

---

* The *thin* sections were made by one of my sons, and the *camera-drawings* by another.

† To follow the meaning of the parts displayed by these sections it is necessary to keep the form of the head of the undissected Lamprey before the eye (Plate 8, figs. 11–13) and also the structure of the cranio-facial apparatus as displayed by the *dissections and solid sections* (Plates 18 and 23).

2nd Section (Plate 20, fig. 2).—The first "lateral upper labial" (*u.l''.*) is now cut across under the median plate (*u.l'.*); the annular cartilage ($l.l^1$.) is now lower and more bent outwards, and the lateral lower labial ($l.l^2$.) is smaller. The fore end of the tongue and its teeth (*tg., l.t.*) is shown in the arched oral opening; here the *roof* of the oral opening is seen to be formed by the great upper labial, but the *disk* grew some distance in front of this part.

3rd Section (Plate 20, fig. 3).—In this section the remarkable imbrication of the cartilages is shown, and, looking at the side view (Plate 18, fig. 1), we see what parts have been cut across. The large overlapping trabecular cornu (*c.tr.*), the great size of which seems more remarkable in the sections than in the dissections, is thin here at its fore edge, well arched, and is much wider than the great azygous labial. That cartilage (*u.l'.*) is very similar in its sections for some distance; it is too much arched to be quite concentric with the great cornu, and its edge is thickened or ribbed, and turned slightly inwards. Following the line of its incurvation below, we see the small front lateral style (*u.l''.*), sharp above and rounded below. Here, in the upper part of this large portico, under the median labial, we see again the front outline of the great broad-ended tongue (*tg.*), which widens upwards, and has a concave upper outline. On each side of the severed part of skin, at the base of the tongue's tip, the annular cartilage ($l.l^1$.) is cut through as it thickens towards its hind part; its section is lobulate above, and sharp below, the sharp part being invested with yellow horn—part of the dental series.

---

* Whilst describing these sections of the disk, it may be well to say that it is formed by a great hypertrophy of the *lower lip*, which grows forwards, closes over the narrowed oral opening, and unites above that opening with the upper lip (see Plate 8, figs. 11–13). Hence the cartilages behind the disk lie in the substance of the *chin* and *throat*, and evidently do not belong to the labial category. The cartilages now referred to are the "distal mandibulars," single and paired. The five cartilages under the cornu trabeculæ are formed in the upper lip, which is a large hood from the first (Plate 1, figs. 1–3). The upper and lower lips of the Lamprey are now seen to be much more (vertically) symmetrical than they seemed to be; above, there is one main azygous piece and two pairs of lesser pieces; below, one main azygous piece and three pairs of subsidiary pieces.

4th Section (Plate 20, fig. 4).—Both the cornu trabeculæ (*c.tr.*) and the median upper labial (*u.l*^{1}.) are broader than in the last, and the first lateral cartilage (*u.l*^{2}.) is cut through obliquely lower down. The annular cartilage (*l.l*^{1}.) is cut across in front of its hind margin, and shows the concavity along its upper half. The hinder teeth (*l.t.*) are shown in the hollow of the divided labial disk. At the upper edge of the annular cartilage, right and left, there is a reniform tract of cartilage; this is the head of the lateral distal mandibular (*l.d.m.*). The skeleton of the tongue (*tg.*, *b.hy*′.) is now cut across, it is a thick slab of cartilage, with both surfaces slightly concave, and the lower face of less extent than the upper.

5th Section (Plate 20, fig. 5).—This is from behind the annular cartilage, and through the hinder third of the great disk (*s.d.*). The two great roof cartilages (*c.tr.*, *u.l*^{1}.) are very similar to the last, and the first lateral upper labial (*u.l*^{2}.) is cut through near its lower end, and the foremost point of the second (*u.l*^{3}.) is cut across. The lateral distal mandibulars (*l.d.m.*) are now flat, with their upper edge turned outwards; between them, and near to them, arching over the hind part of the disk, two plates of cartilage are cut through, thick in the middle and thin outside; these are the two sides of the fore part of the "median distal mandibular" (*m.d.m.*), which is notched in its broad fore edge (see Plate 10, fig. 6) in the young *P. marinus*. Several cartilages are seen in the fore end of the tongue (*tg.*); of these the four larger tracts belong to the basi-hyal (*b.hy.*, see also Plate 18, figs. 6–8); the short anterior median (*b.hy*′.), with the pair of short ascending pieces (*b.hy*″.), and behind and under the middle piece the fore end of the main long bar (*b.hy.*), which is elliptical in section in front, and placed with its long axis upwards. This section shows, what the general view of these parts does not, namely, that when these curious *quasi-mandibles* are cut through obliquely, their common basal piece is arched a little upwards. In the curious lingual *cushions* there is a small "supra-lingual" cartilage, right and left (*s.l.c.*); its point is cut across here.

6th Section (Plate 20, fig. 6).—The use of these various sectional figures will be seen by comparing this with the last; there seems to be but little difference between them, but we miss some things seen in that, and find some new ones in this. The great leafy cornu (*c.tr.*) is wider and flatter, the median upper labial (*u.l*^{1}.) is very similar; the first lateral upper labials are gone, the section was made behind them, and the second (*u.l*^{3}.) are larger points of cartilage between the two roof-plates. The flattened distal lateral mandibulars (*l.d.m.*) are vertical here, and the median cartilage (*m.l.m.*) is a single plate, slightly bent downwards where the basi-hyal rests on it. The main basi-hyal (*b.hy.*) is now much flatter and somewhat higher; the front short middle piece is not seen, but the erect pieces (*b.hy*″.) are cut across in their hind lobe, so that there is a considerable space between them and the main bar. The little cartilages inside these (*s.l.c.*) are larger, are elliptical in section, and in the valley between the cushions that contain them, sharp yellow teeth are seen—the "supra-lingual" teeth (*s.l.t.*) (see Plate 14, fig. 9).

7th Section (Plate 20, fig. 7).—In this, the same parts are cut through as in the last, but they are different in form and position. The great cornu (*c.tr.*) is but little changed, but the median labial plate (*u.l*^{1}.) is considerably contracted, at this, its hinder margin. We see the wedge-like point of the second lateral upper labial (*u.l*^{3}.) above, and the paired distal mandibulars (*l.d.m.*) below; these are getting further apart. The median piece (*m.d.m.*) is now much narrower, being severed behind its dilated part; the main basi-hyal is as in the last, but its wings (*b.hy″.*) are vertical in this section, and so are the small supra-linguals (*s.l.c.*) between them; we still see the teeth (*s.l.t.*) between the cushions. The section of the great disk is lessening towards its hind margin.

8th Section (Plate 20, fig. 8).—The oral opening is now becoming very contracted, the great roofing cornu (*c.tr.*) is of undiminished size, but the large median labial (*u.l*^{1}.) only shows its postero-inferior angles, right and left. The second lateral pair (*u.l*^{3}.), which wedges in between the two roof-pieces, is now trilobate in section, and larger; the distal mandibulars (*m.d.m.*, *l.d.m.*) and main basi-hyal (*b.hy.*) are much as in the last section, but the paired lobes of the basi-hyal are gone; only a small part of each supra-lingual (*s.l.c.*) is seen.

9th Section (Plate 20, fig. 9).—The roofing cornu (*c.tr.*) is narrower here, and its lower edges are thickened instead of being sharp. The upper median labial is not seen, but the second lateral piece (*u.l*^{3}.) is now a large slab; it is *f*-shaped in section, vertically placed, thick edged above and thin below. The distal mandibulars (*m.d.m.*, *l.d.m.*) are smaller, and so are the supra-linguals (*s.l.c.*); the main basi-hyal (*b.hy.*) keeps its form. This section is through the last fold of the suctorial disk, which is here seen to be quite free from the rest of the section, and to have lost its lower gap.

10th Section (Plate 20, fig. 10).—This section is behind the lips, and only one pair of labials, the second upper lateral (*u.l*^{3}.) are cut across; they are thinner here than in the last. The great cornu (*c.tr.*) is one-third narrower; the distal mandibulars (*m.d.m.*, *l.d.m.*) are getting less and less; the main basi-hyal (*b.hy.*) is much the same, and the tongue (*tg.*) is cut through behind the cartilages and teeth.

11th Section (Plate 20, fig. 11).—The great cornu (*c.tr.*) is gaining in thickness, but losing its width; the second lateral labials (*u.l*^{3}.) are cut through their hind margin; the other parts are much as in the last section. The small elevation at the top is the beginning of the nasal opening (*e.n.*).

12th Section (Plate 20, fig. 12).—In this section the outer nasal opening (*e.n.*) is laid open above the proximal part of the cornu trabeculæ (*c.tr.*). Here the oral cavity (*m.*) is a large oblong space, partly occluded, below, by the lingual apparatus, in the base of which we see the vertical basi-hyal (*b.hy.*). Opposite the middle of that bar the postero-inferior angle of the large lateral labial (*u.l*^{3}.) is cut across, and the points of the three distal mandibulars (*m.d.m.*, *l.d.m.*) are still seen in section.

13th Section (Plate 21, fig. 1).—This is also through the outer nasal opening (*e.n.*) and the proximal part of the cornu (*c.tr.*); the other sections are like the rest, except that the lateral distal mandibulars are no longer seen.

14th Section (Plate 21, fig. 2).—The outer nasal passage (*e.n.*) is a flattened tube, vertically placed, here, for this is close in front of the nasal capsule, and through the junction of the cornu (*c.tr.*) with the solid pre-cranial plate or ethmoid; the cartilage lies over the large oral cavity (*m.*) as a thick beam, slightly arched upwards, and a little hollowed in the middle, above. The other points of cartilage are like the last.

15th Section (Plate 21, fig. 3).—This section is through the front third of the nasal capsule (*ol.*), showing its *nine pairs* of radiating folds or lobes, each having its own fissure, and lined with mucous membrane; the interspaces of the folds are filled with black pigment. The lower folds are shorter than the upper and lateral, and the posterior nasal canal (*p.n.c.*) is distinct; it is seen as a transversely oval space between the capsule and the ethmoid (*eth.*). The capsule itself (*na.*) is not so distinctly bilobed as in the young of *P. marinus* (Plate 18, fig. 3, *na.*), for its top is flat, and it is somewhat angulated at the sides. The cartilage of the capsule is of the softer kind, but approximates to the general hardness of the skeleton in the hind part; it does not meet below in the sections that cut through the folds,—only behind (fig. 6). It is not a mere *grating* as in the Myxinoids (Plates 10 and 17), but is a continuous sheet, dipping in towards the deeply pigmented interspaces of the folds. The cranium is cut through so as to show the continuity of the ethmoid (*eth.*) with the *ethmo-prepalatine* tract (*e.pa.*), running almost to the front spike. The whole of this arched, but flat-topped, tract is of nearly uniform thickness; the palatine bars bend a little inwards above, and then outwards below, and are rounded at their edge. Under the oral cavity (*m.*) the only cartilages cut through are the basi-hyal (*b.hy.*) and the tip of the median distal mandibular (*m.d.m.*)

16th Section (Plate 21, fig. 4).—This is through the middle of the nasal capsule (*na.*, *ol.*) and the fore part of the eye-ball (*e.*). The wheel-like appearance of this organ is most perfect here, the lower folds being larger; and the lower face of the capsule, which is membranous for a slight extent, is not pushed up by the posterior nasal canal (*p.n.c.*). On each side of the ethmoid (*eth.*) there is a low wall, the beginning of the orbito-sphenoidal region, and in the middle of the descending plate of cartilage there is a fissure,—this is the fore margin of the "subocular fenestra" (*s.o.f.*); the pterygo-palatine bar (*pt.pa.*) is thickened at its lower edge. The lining of the mouth (*m.*) is quadrilobate; under it is the only other cartilage seen in this part—the basi-hyal (*b.hy.*). The third branch of the 5th nerve (V^3.) is seen in section between the subocular fenestra and the oral cavity.

17th Section (Plate 21, fig. 5).—This is through the back of the nasal organ, and only two pairs of upper folds are laid open, the rest of these folds being covered here by the highly pigmented stroma; the cartilaginous capsule (*na.*) reaches below to the lowest fold, right and left. The cranium at this part is four-winged, for the ethmo-palatine (*e.pa.*) is much less here, because of the large space—the subocular fenestra—(*s.o.f.*), and the orbito-sphenoidal wings (*o.s.*) are rising and diverging; in the hollow between them runs the posterior nasal canal (*p.n.c.*, outline not figured in this section). The post-palatine and pterygoid at their junction form a moderately high and thickish band; inside this, near its top, is the third branch of the trigeminal (V^3.); below the oral cavity (*m.*) is the basi-hyal (*b.hy.*).

18*th Section* (Plate 21, fig. 6).—Here we see that the apiculate hind part of the nasal capsule (see also Plate 18, fig. 3) grows vertically downwards for some extent, and that the walls, which underlaid the capsule to some degree, further forwards, have now united to form a perfect floor. The median cartilage is partly hard; it does not correspond with the *ethmo-septal* partition of higher types, but with so much of the nasal roofs as are developed downwards, back to back, to unite with the true septum. The posterior nasal canal (*p.n.c.*) is seen in the, bottom of the deep cranial trough, whose orbito-sphenoidal walls (*o.s.*) are high and diverge so as to make a wide space for the olfactory lobes (C^{1b}.), and the curious limited partition and floor of the nasal capsule (*na.*). Here the *waist* of the skull is well pinched in, and the orbits and eye-balls (*e.*) are large; large, also, is the shelving floor of the orbits, which is cartilage above and below, the intermediate space being equal in extent to both of the tracts; the upper is now trabecular (*tr.*), and the lower pterygoid (*pg.*); the space, or suborbital fenestra (*s.o.f.*), is split into two laminæ, and between them the 3rd branch of the fifth (V^3.) passes to the lower and front parts of the face.

The oral lining (*m.*) has now become five-lobed; below it, we see the vertical basi-hyal, and close to it a pair of cartilaginous points—the fore ends of the cerato-hyals (*c.hy.*) (see also Plate 18, figs. 1, 2, 6, 7).

19*th Section* (Plate 21, fig. 7).—This is through the middle of the eye-balls (*e.*), behind the nasal capsule, where the olfactory lobes (C^{1b}.) arise from the fore brain. The dura mater (*d.m.*) is thick, and still retains the form of the back part of the nasal capsule, and below this membrane's roof we see that the side walls (*o.s.*), which are gently out-turned above, are segmented below their middle, opposite the top of the posterior nasal canal (*p.n.c.*). This is the beginning of the orbito-sphenoidal fenestra (*o.s.f.*), which membrane is perforated further backwards for the optic nerve (see Plate 18, fig. 5). The subocular flange of the trabecula (*tr.*) is smaller than in the last; the remaining parts are quite similar in both sections (*pg.*, *s.o.f.*, V^3., *b.hy.*, *c.hy.*).

20*th Section* (Plate 21, fig. 8).—Here the section is through the optic nerves and the fore brain (II., see also fig. 9, C^1.), where the orbito-sphenoidal fenestra (*o.s.f.*) is wide. The dura mater (*d.m.*) is still thickened in the middle of the roof, and the orbito-sphenoids (*o.s.*) now turn in above. The trabecular flange (*tr.*) is very thin, right and left, and so also is the trabecular floor, now behind the intertrabecular region. This is the last section figured in which we shall see the posterior nasal canal (*p.n.c.*) fairly lodged *inside* the cranial cavity. The remaining parts are like what was shown in the last, but the pterygoid band (*pg.*) is broader. The fibres of the 3rd branch of the 5th nerve (V^3.) have not escaped the layers of the floor at this part.

21st Section (Plate 21, fig. 9).—The whole cranio-facial frame is here seen as mere patches of cartilage, three pairs of small convexo-concave tracts above, with one large trilobate, and two small pyriform, sections below. Here the cranial cavity is large, but the cerebrum (C^1.) is small; the orbito-sphenoids (*o.s.*) are separated from the trabeculæ (*tr.*) by a space (*o.s.f.*) wider than the bars themselves. These are bent in the opposite direction, the upper are convex outside and the lower concave. The pterygoid (*pg.*) is a gently-arched band; between it and the trabeculæ (*tr.*) the 3rd branch of the 5th (V^3.) is seen lying on the fenestra, ready to enter. The posterior nasal canal (*p.n.c.*) is now without a cartilaginous floor, ready to escape into the pharyngeal space; the cartilages below the buccal cavity (*m.*) are the basi- and cerato-hyals (*b.hy.*, *c.hy.*). Above these the rising floor of the mouth contains the *fimbriated intervelar shelf* (see Plate 18, fig. 7; and Plate 14, fig. 8).

22nd Section (Plate 22, fig. 1).—This shows a pyriform cranial cavity containing the fore brain (C^1.) at its junction with the mid brain. Here the back part of the eye-balls (*e.*) and the orbital muscles are seen, and the posterior nasal canal (*p.n.c.*) escaping through the pituitary space between the trabeculæ, which form at this part the high alisphenoidal walls (*al.s.*), in section like a pair of callipers, bent outwards, above, like blades, which are connected across the roof by the convex dura mater (*d.m.*). This section is through the hind part of the subocular fenestra; the pterygoid (*pg.*) is here thick above; the 5th nerve is not figured in this drawing. Below the lobulated oral (or *buccal*) cavity (*m.*), and between that space and the hyoid apparatus, there is a plate of hard cartilage cut across—a thinnish, sinuous tract. This is the "intervelar shelf" (*i.v.s.*), cut across behind the fimbriations. Here the cerato-hyals (*c.hy.*) are much deeper than in the last section.

23rd Section (Plate 22, fig. 2).—Here, if anywhere, we have an instructive section, made in the pre-auditory or post-pituitary region. The mid and hind brain (C^2., see also fig. 3, C^3.) meet here, and the latter is giving off the great trigeminal nerves (V.), with their huge gasserian ganglia. These parts are seen in the foramen ovale, under the fore face of the auditory capsule (*au.*) which is surmounted by the alisphenoid (*al.s.*), now turning inwards on to the roof of the skull. Looking at this figure and that of the dissected skull (Plate 18), we see that the razor has cut through the investing mass (*iv.*) enclosing the fore part of the notochord (*nc.*), the pedicles (*pd.*), the back part of the pterygoid (*pg.*), that part of the suspensorium (or *pterygo-palatine arcade*) which gives off the epi-hyal from its hinder margin (see Plate 18, fig. 1, *e.hy.*). Below the basis-cranii, the posterior nasal canal (*p.n.c.*) has nearly doubled its "bore;" at some distance below that tube we see, now, not a wide quinquelobate *buccal cavity*, but the plicated opening of the narrow food-pharynx (*phx.*), having under it the cartilaginous core of the intervelar shelf. Below that shelf we see the hyoid apparatus; the fissures between that musculo-cartilaginous structure and the shelf form the valvular entrance to the *branchial canal* (or "bronchus;" see also Plate 23, fig. 1). Here the cerato-hyals (*c.hy.*) are seen to be obliquely-placed plates, sinuous in form, and bent upwards, both externally and within, where they are tied to the carinate basi-hyal (*b.hy.*) (see also Plate 18, figs. 2, 6, 7).

24*th Section* (Plate 22, fig 3).—The cranial cavity is nearly surrounded by cartilage in this part, for the alisphenoids nearly meet as a *tegmen cranii* (*t. cr.*) over the hind part of the mid brain (C^2.). The hind brain (C^3.) is also cut across in its fore part, and the hind part of the 5th nerve (V.) is still to be seen in the foramen ovale. The auditory capsules (*au.*) have here an inner wall in front of the meatus internus. The section of the notochord (*nc.*) is larger; there is a fissure between the two parachordal plates (*iv.*) above; these plates pass, with but little thinning out, directly into the pedicles (*pd.*) The section is made through them into the hyoid bar (*e.hy*), which is gently bowed outwards, enlarges, and again lessens before it is turned forwards and inwards, as the cerato-hyal. Just above its middle an *elbow* is seen; this is the back of the pterygoid bar (*pg.*), *whence the quadrate lobe and condyle should have grown outwards and downwards.* The cerato-hyal *region* is suddenly bent upwards with its convex face downwards; each bar ends at a moderate distance from the median carinate rod (*b.hy.*). The posterior nasal canal (*p.n.c.*) is still larger than in the last section, and is sub-pentagonal in outline. Below it is the very narrow pharynx proper (food-pharynx, *phx.*), with its puckered, contracted lining, and below this is the body of the cartilage in the "intervelar shelf" (*i.v.s.*). The space below, right and left, is where the buccal cavities are passing into the branchial canal (see also Plate 23, fig. 1).

25*th Section* (Plate 22, fig. 4).—This is through the meatus internus, and shows the 8th nerve and its ganglion (VIII.) The capsule (*au.*) is continuous above, as in the last, with the alisphenoidal tegmen (*t.cr.*) over the hind brain (C^3.), and also, below, with the thick parachordals (*iv.*), which have now a larger notochordal section (*nc.*) within them. The basal cartilage is cut through here, behind the pedicle, but the corresponding region of the hyoid arch is suppressed, for there is no hyomandibular tract, such as we see in the Myxinoids; beyond this point there is no more *endoskeletal* cartilage in the side walls. The lower part of the epi-hyal and the cerato-hyal (*e.hy.*, *c.hy.*) are cut through, and also the basi-hyal (*b.hy.*) Above the cerato-hyal we see the crura of the intervelar shelf (*i.v.s.*) cut across the pedate end, so that the *toe* and the *foot* are separate points of cartilage (see Plate 18, fig. 7, *i.v.s.*) The section of the posterior nasal canal (*p.n.c.*) is mutilobate and large; under it the food-pharynx (*phx.*) is very small, with its mucous lining corrugated, and in the space below it we have the beginning of the special branchial canal (see also fig. 5, *br.c.*).

26*th Section* (Plate 22, fig. 5).—This is behind the meatus internus and the alisphenoidal roof; the hind brain is seen to be very small as compared with the cranial cavity. As in the last, the notochord (*nc.*) is roofed by the investing cartilage (*iv.*), but the floor is imperfect. The fore part of the vagus, with its ganglion (X.), is seen, and below it, that part of the extra-hyal (*ex.hy.*) which fastens on to the top of the epi-hyal bar is cut across, and, lower down, the main bar of this superficial soft band. The angle of each cerato-hyal (*c.hy.*) is cut across and the basi-hyal in its *basi-branchial region* (*b.br.*). Three cavities are severed, lined with mucous membrane, one above another, in the mid-line—these are the posterior nasal canal (*p.n.c.*), the pharynx, proper (*phx.*), and the opening of the branchial canal (*br.c.*).

27*th Section* (Plate 22, fig. 6).—This is through the hind face of the auditory capsule (*au.*) and the main mass of the vagus nerve (X.) Here the notochord (*nc.*) is floored, but not roofed, and the limited investing cartilage (*iv.*) does not reach the auditory capsule, but leaves a space for the vagus to pass through; thus the roof of the skull is gone, and most of the side walls. The extra-hyal is cut across as it goes back to join the general basket-work; the basi-hyo-branchial region is cut through (*b.hy.*), and the angles of the cerato-hyals (*c.hy.*). The posterior nasal canal (*p.n.c.*) is lessening; below it we see the food-pharynx (*phx.*), below it the branchial canal (*br.c.*), and right and left of these passages the branchial folds of the first pouch (*br.p.*)

28*th Section* (Plate 22, fig. 7) is from the fore part of the spine, and through one of the foremost pairs of neural arches (*n.a.*), which are seen to be large wedges of hard cartilage, with their upper end thick, and their lower end sharp, the section not reaching to their base. The notochord (*nc.*) has now its average size; its sheath is a thick laminar membrane, like the cornea of the Mammalian eye-ball. The other part of the endoskeleton is the basi-branchial bar (*b.br.*) imbedded in the lingual muscles; above these masses are the branchial canal (*br.c.*), the proper pharynx (*phx.*), and the posterior nasal canal (*p.n.c.*) Outside the gill pouch (*br.p.*, 1st or 2nd) the extra-branchial basket-work (*ex.br.*) is cut across in *nine* places; above, near the notochord, the longitudinal band uniting the arches above; then, on the upper convexity, one of the spurs; at a distance below this the upper, and then the lower, cross band defending the aperture; and then, below, one continuous tract of cartilage belonging to the lower part of a right and left arch, at their junction.

29*th Section* (Plate 22, fig. 8.)—This is very similar to the last section, and was taken not much further back. Here in a complete section of the neural cartilages (*n.a.*), we see that they are thickened at both ends. The posterior nasal canal (*p.n.c.*), is much folded; this is its last appearance in the sections figured; the other passages are as in the last section. The upper band of the basket-work (*ex.br.*) is cut across, also one of the snags, and one of the cross bars; the other must have been cut through, but was hidden beneath the other tissues. Below, the common junction of the bars is cut across, between the bars, and between the median fenestræ.

30*th Section* (Plate 22, fig. 9).—Here we see the neural cartilages (*n.a.*) resting upon the sheath of the notochord (*nc.*); below this the great artery (*ao.*) is cut across, but there is no posterior nasal canal between it and the pharynx (*phx.*), which is well marked off from the branchial canal (*br.c.*) The lingual apparatus and the basi-branchial (*b.br.*), is still present; this is at about the *first third* of the great branchial apparatus. Here the upper extra-branchial bands (*ex.br.*) are cut across; the uniting bands above and under the aperture; and the median inferior junction of the arches.

31*st Section* (Plate 23, fig. 4).—This is the last of the thin sections figured, and is from the beginning of the *second third* of the branchial region; both the external apertures (*e.b.a.*) are laid open. The neural arches (*n.a.*) are not so wide apart above, and they have crept some distance down the side of the notochord; under these hard tracts the soft upper bands of the basket-work (*ex.br.*) are cut across, then two of the lesser bars, then a main bar, bending inwards behind its own aperture (see Plate 18, fig. 1), and then a common inferior band at a very narrow part. The passages between the pouches are the great artery (*ao.*), the pharynx (*phx.*), and the branchial canal (*br.c.*); the median basi-hyobranchial bar is not seen, but the hind part of its huge muscular lingual apparatus is shown.

32*nd Section* (Plate 23, fig. 5).—This is the first of the transversely-vertical solid sections, made a little obliquely so as to show the external branchial aperture, the last, on one side (only) with a few of the folds (*br.p'.*). The small flat myelon (*my.*) is seen in the canal formed by the theca vertebralis (*th.v.*), and under it the notochord (*nc.*) is at its largest size. The heart (*h.*) is cut through in its fore-part, with the basket-work of the pericardial region (*pcd.c.*) cut across. The pharynx (*phx.*), at the end of the branchial canal, is larger, but is pushed out of the mid-line by the heart. This section is between two pairs of neural arches.

33*rd Section* (Plate 23, fig. 6).—The second of these solid sections is through the middle of the heart (*h.*), and shows the extra pericardial (*pcd.c.*), as an almost perfect girdle; here the opposite face of the section has been drawn, so that the pharynx (*phx.*) is seen on the other side; the tips of two neural arches (*n.a.*) have been cut through.

34*th Section* (Plate 23, fig. 7).—Here we see the fundus of the tilted *bowl*, the pericardial cartilage (*pcd.c.*); the pharynx is in the figure on the same side as in fig. 5, the same *face* of the section being drawn; only the tips of a pair of neural arches are cut across. The muscular masses in these three figures are shown in their full (uncontracted) bulk.*

On the skeleton of the embryo of Petromyzon planeri, 7·8 *mm. to* 9·5 *mm. in length.*

These small, delicate, worm-like embryos, the larger of which only, namely, those about $\frac{1}{3}$-inch long, were worked out by me, came to me through Professor F. M. BALFOUR, who was enabled to breed them (by artificial impregnation) through the kindness of OSBERT SALVIN, Esq., F.R.S. The sections were lent me by Professor BALFOUR, and what I have to show with regard to them may be added to his excellent account of the development of this type in the 2nd vol. of his 'Comparative Embryology' (pp. 68–83, figs. 37–49).

---

* SCHNEIDER (plate 10, fig. 1) shows the cartilages of the tail-fin: these parts do not enter into my plan.

My figures are from one of the larger of these embryos (Plate 8, figs. 1–3); in the full-figure, the side view, about *eighty* myotomes are shown; its great approach, in form, to the proper larva (or *Ammocœte*) is seen by comparing the next figures (4–6) in the same plate.

Dissection of the skull of an embryo of Petromyzon planeri, 7·8 *mm. long.*

As this is the lowest kind of primordial skull worked out at present by me, I shall compare it with that of (A) the Ray;* (B) the Sturgeon; (C) the Lepidosteus; (D) the Salmon; (E) the Axolotl; and (F) the Larval Frog and Toad.

The large notochord (Plate 25, fig. 7, *nc.*) is almost straight; in an earlier stage (BALFOUR'S 'Embryology,' pp. 74, 75, figs. 42, 43) it is turned downwards at its fore end, and this bend is retained throughout life (Plate 23, fig. 1); it now reaches further forwards, relatively, than afterwards, and gradually lessens to a blunt point. Further than the hind margin of the pituitary space (*py.*) it does not go. Taking the hind margin of the auditory capsules (*au.*) as our place of measurement, behind, and the fore end of the trabeculæ (*tr.*) as another, in front, the notochord reaches exactly half way.

Measured thus some time after transformation (Plate 18, fig. 4, *nc.*, *tr.*) the notochord is about two-fifths the length of the basis cranii; thus we see that it remains as an important basi-cranial structure, but in its earliest development it shows nothing of the *cephalo-chordal* character of *Amphioxus*. The membranous sheath of the notochord is very thick at this early stage; at no stage have I found true cartilage in it, such as we see in the Elasmobranchs. The primary basi-cranial cartilages (*iv.*, *tr.*) are *para*-chordal for their hinder three-fifths, and *pro*-chordal for their front two-fifths, but the front part is thick and wide, whilst the hind part attenuates gently to a fine, pointed end; these two ends are, however, far back behind the ear-capsules; two-fifths of the parachordal length of the cartilage is behind the ear. Considering the size of the region supplied by the branches of the vagus nerve, it is not unreasonable to take all the parachordal region of the notochord as properly basi-cranial; the fact is, the head and spine are not divided off sharply—there is no joint; afterwards, when the neural arches appear in the transformed Fish, the first pair of cartilages give us the beginning of the spine.

These parts cling close to the sides of the notochord, so as to be crescentic in section (see Plate 25, figs. 3, 4, *iv.*, *nc.*) nearly to the middle of the auditory capsules (*au.*); thence they diverge further and further from the axial rod. In front of that rod, in their *pro*-chordal part, the bars (trabeculæ) are separated by a tract thrice their greatest width. At this part they embrace the lower part of the front of the membranocranium, in front of the pituitary space.

---

* (A) Trans. Zool. Soc., vol. x., plate 35; (B) Phil. Trans., 1882, Plate 14; (C) Phil. Trans., 1882, Plate 30; (D) Phil. Trans., 1873, Plate 2; (E) Phil. Trans., 1877, Plate 22; (F) Phil. Trans., 1876, Plates 55, 56, and 60; and 1881, Part I.

The basal bars in their pro-chordal region (*tr.*) are thickest in their middle, but do not lessen much in front, they are, in form, like a pair of *callipers*, and end in a blunt point which is turned a little towards its fellow. The bars are tilted upwards and outwards (Plate 24, figs. 1–4, *tr.*; and Plate 25, fig. 2, *iv.*).

A little in front of the auditory capsules we see on each side a small blunt hook of cartilage, turned forwards at its free end, but growing directly outwards from the trabeculæ without any sign of segmentation; these are the primordial rudiments of the pedicle and pterygoid (*pd.*, *pg.*). These *first*, *continuous* rudiments of the face are of great interest, as we shall see by comparing them with their counterparts in other Ichthyopsida.

So also is the condition of the primary basi-cranial bars or trabeculæ, which on their hinder part embrace the notochord as parachordals (or investing mass), but *from the first* are rather related to the fore brain as its proper supporting skeleton, than to any other part. Their union in front of the trabeculæ, and their continuation forwards, as *cornua*, are secondary matters, and vary very much in different types, but their most important character is their *continuity*, for they show no signs of being under the influence of any segmentation that may be developing in the head. Here, the basal bands are longer, but much narrower, in their parachordal than in their prochordal regions, but in the nearest relations of these *Petromyzoids*, the "Anura," they only embrace the apex of the notochord by their hinder end, and form their cornua before they unite at the mid-line. In those Amphibia the parachordal region is developed as a backward extension of the trabeculæ, but in the Urodela that part is developed independently, and the cornua trabeculæ may appear first as *ongrowths* of the trabeculæ, or afterwards as *outgrowths*. Then, as to the facial part of the skull, or upper jaw, (the upper part of the 1st branchial or visceral arch), which is greatly developed forwards over the mouth in all known Vertebrata, we see that in the Lamprey the pedicle with its hooked end or rudiment of the pterygoid cartilage is developed from the first as an outgrowth of the trabecula, and the rest of the arcade—its palatine portion growing on to the ethmoidal end of the trabecula—does not appear until after transformation.

In the Anura the whole arcade is primary, and is primarily one with the trabeculæ, both the pedicle and the ethmo-palatine tract being continuous with the basal bar.

In the Urodela nothing of the sort exists; the pedicle and its ascending process are developed as the bifid free top of the suspensorium; afterwards both unite with the skull in some kinds; in others only the ascending process. In them the palatine with its ethmo-palatine process, is an *early* free cartilage; the pterygoid process of the suspensorium is a *late* outgrowth, and only in one kind known (*Ranodon sibiricus**) does the subocular arcade *become* continuous. On the other hand in the genus *Bufo*, amongst the Anura, after being a mere wing or flying buttress of the skull during the larval period, it becomes, in metamorphosis, broken up into separate parts, like that which is primary in the Urodela.

---

* See Wiedersheim, 'Kopfskelet der Urodelen,' 1877, plate 5, fig. 69.

In the Rays there is a *pedicle*, but it is a primarily independent cartilage, the foremost of the "pharyngo-branchial" elements; in Sharks there is merely *one*, *two*, or *three* "interbranchial rays" in this part, and in all the normal "Elasmobranchs" the palatine region—which has a distinct segment in Rays but not in Sharks—is suspended to the skull by a ligament. In these types the trabeculæ are flat and wide, and chondrify first; afterwards, the parachordals become cartilaginous, but this condition runs on into the spinal region without any break, until the *occipito-atlantal* joint is formed.

In *Acipenser*, a low type of Ganoid, the whole basi-cranial region is chondrified at about the same time, but in form is similar to what is seen in the Elasmobranchs. But the upper jaw is developed quite independently of the basis-cranii; its upper part, answering to the pedicle (or metapterygoid region), is a mosaic of cartilaginous pieces, with a median row, such as is seen in the *ventral aspect*, only, of the arches, in other types.

Lepidosteus, a high Ganoid, comes nearer to the Suctorial Fishes and the Tadpole, for the palatine end of the upper jaw (palato-quadrate) is from the first continuous with the fore end of the trabecula, and so also is the pier (or *pedicle*) of the hyoid arch. In that type I find no precedence of the prochordal tracts (trabeculæ) in their chondrification; they, and the parachordal tracts, are one, and show no signs of distinction from the first.

It is therefore evident that there is to be seen, in the early chondrocranium of the various *Ichthyopsida*, a mixture of the *non-essential* and the *essential*; these have to be winnowed apart by the Morphologist. I must return to this subject in my summary; but it is manifest that the primary cranium exists merely as a pair of supporting bands from which, without segmentation, the *facial* skeleton may grow. The cartilages that arise in the intermuscular septa, in the spinal region, as rudiments of vertebræ, are a *late* product in the evolution of a Vertebrate; they possibly had no existence in countless types, the brain of which had appeared in its three main vesicles, which, becoming larger and heavier, acquired *pro-* and *para*-chordal supporting balks.

We saw (in Part I.) that one type of Fish, the Hag, more than a foot long, and as thick as a finger, with a highly complex cranio-facial apparatus, has no vertebral rudiments. This is true, also, of another (*Bdellostoma*), as thick as the wrist, and almost a yard long.

This *Myxinoid* condition remains throughout larval life in the Lampreys, and exists for a time, after the development of the basi-cranial bars, in the other *Ichthyopsida*.

In the figure given of the embryo Lamprey's skull (Plate 25, fig. 7; V., X.) I have shown the huge size of the ganglionic mass belonging to the 5th nerve (possibly that of the 7th included in this mass), and of the 10th or vagus.

The auditory capsules (*au.*) are evenly oval in form, and except where the 8th nerve enters, are covered with a thin layer of true cartilage, which, however, like the rest, is *soft*, at present.

The only skeletal part formed inside the head cavities and branchial arteries is the pedicle, with its hooked pterygoid rudiment (*pd.*, *pg.*); this state of things continues until the time of transformation.

But the extra-branchial basket-work is one of the first parts to be developed, as the sections now to be described show; the pattern of the basket-work is figured from a later stage (Plate 25, fig. 8), but it merely differs from that of these embryos in size and a somewhat increased density and strength of the cartilage. The sections now to be described will be better understood by reference to a figure of BALFOUR's (vertical section of an embryo half the size of those from which these transverse sections were made) (see 'Comp. Embryol.,' p. 75, fig. 43).

Vertically transverse sections of the head and branchial region of embryos of P. planeri, *7·8 mm. and 9·5 mm. in length. Magnified* 150 *and* 300 *diameters.*

1st Section (Plate 24, fig. 1, 150 diams.; see also Plate 8, figs. 1–3).—This is through the fore brain (C^1.) and upper lip (*u.lp.*) of the larger embryo. Here the huge relative size of the brain is shown, filling the membrano-cranium. The parts which concern us at this part are the thin tilted ends of the trabeculæ (*tr.*), which are lanceolate in section, and are connected together by a definite tract of soft cells. In part of a similar section of the smaller embryo (Plates 24, fig. 1*a*, 300 diams.) we see that the cartilage is two cells thick in the middle, and that the intervening soft tract is in two layers near the cartilage, ready to form the trabecular commissure (see Plate 19, figs. 4, 5, *tr.*).

2nd Section (Plate 24, fig. 2, 150 diams.).—This is still through the upper lip (*u.lp.*), the fore brain (C^1.) is somewhat smaller at this part, the trabeculæ (*tr.*) are now oval in section, and the special layer of indifferent cells, ready to become a transverse band of cartilage, is not seen. In a partial section of the lesser embryo at this part (Plate 24, fig. 2*a*, 300 diams.), the young cartilage (*tr.*) is three cells thick.

3rd Section (Plate 24, fig. 3, 150 diams.).—This is through the fore brain (C^1.) behind the upper lip, and therefore through the chin (see Plate 8, figs. 1–3); the tilted trabeculæ (*tr.*) are broader than in the last section.

4th Section (Plate 24, fig. 4, 150 diams.).—In this section, through the hind part of the fore brain (C^1.) and the pituitary region (*py.*), the trabeculæ (*tr.*) are thicker and less tilted; this is immediately in front of the Gasserian ganglion.

5th Section (Plate 24, fig. 5, 150 diams.).—This is through the mid brain (C^2.); the fore part of the Gasserian ganglion is cut across, and also the stem of the 5th nerve (V.) as it passes over a tract of cartilage growing directly from the cartilage (*iv.*). The notochordal apex (*nc.*) is cut across close behind the pituitary region. Another figure (Plate 25, fig. 1, 300 diams.) shows the basis-cranii and its facial outgrowths on a larger scale. The oval section of the cartilage (*iv.*) lies in a nearly horizontal position and is three cells thick, whilst the hooked rudiment of the pedicle and pterygoid (*pd.*, *pg.*) is two cells thick, with an intercalary cell or two at its bulbous end; its cells are smaller than those of the trabecular bar, but they are only a slight degree behind them in development, and there is no segmental line between them. What appears to be such a line is due to the difference in the size of the cells in the main and secondary bars. The notochord (*nc.*) is cut across; the mouth cavity (stomadæum) is very large.

6th Section (Plate 24, fig. 6, 150 diams.).—This is through the mid brain (C^2.) and the massive Gasserian ganglia (V.); the notochord (*nc.*) is enlarging, and the basal bars or parachordals (*iv.*) are much nearer the notochord than in the last, and they are circular in section. Here, right and left, there is a curtain hung across the back of the *stomadæum* (*m.*), partly dividing it from *the archenteron*. This is the "velum" (*vl.*), (see also Plate 25, fig. 10, *vl.*).

In a partial section, intermediate between this and the last (Plate 25, fig. 2, 300 diams.), the cartilages (*iv.*) are further from the notochord, still oval in section, and three cells thick in their middle.

7th Section (Plate 24, fig. 7, 150 diams.).—This is in the fore part of the hind brain (C^3.) and the fore third of the auditory capsules (*au.*); it is in front of the meatus internus; the capsules are oval in section, are a little flattened on their inner face, and slightly tilted outwards, above.

This is between the large *pre-* and *post*-auditory nerve-ganglia. The narrow terete parachordals (*iv.*) are midway between the capsules and the enlarging notochord. The space below is now *pharyngeal* (*phx.*).

A similar, but partial, section made behind the entrance of the auditory nerve (Plate 25, fig. 3, 300 diams.), shows that the membranous labyrinth (*au.*) is covered with a thin (single) layer of cartilage cells. Here the moieties of the investing mass (*iv.*), or parachordal tracts, are crescentic, and cleave close to the membranous sheath of the notochord (*nc.*).

8th Section (Plate 24, fig. 8, 150 diams.).—The hind brain (C^3.) is becoming smaller, for this is at the back of the auditory capsule (*au.*). Below, between the membrano-cranium and the capsule, the ganglion of the vagus (X.) is cut across. Here, also, the investing mass is in crescentic sections, cleaving close to the enlarging notochord (*nc.*).

Part of a similar but partial section (Plate 25, fig. 4, 300 diams.) shows the relations of these parts, and the form of the double row of cartilage cells, right and left.

9th Section (Plate 24, fig. 9, 150 diams.).—This is a very instructive section, made through the first pair of branchial pouches and their openings at the end of the hind brain (C^3.) behind the auditory capsules, but through the vagus ganglia (X.). There is still a definite tract of parachordal cartilage (*iv.*) embracing the notochord (*nc.*), and considerable tracts of the first extra-branchial (see also Plate 25, fig. 8, $ex.br^1$.) come into view. On one side the top of the arch is cut through, where it runs in the longitudinal upper band, and the section of that band lies close to, but is independent of the investing mass (*iv.*). Part of the arch, above, is seen on the other side and on both sides the bounding bars of the external branchial opening—on one side directly across, and on the other obliquely; in the former (the left side of the figure) the inturned middle part of the main arch is seen for some extent, and then some of its lower part. The inner wall of the first pair of branchial pouches is cut through somewhat irregularly, a thing not to be wondered at, considering the *size* of the fish sectioned.

10*th Section* (Plate 25, figs. 5 and 6, 150 and 300 diams.).—This is through the *third* or *fourth* pouch and the middle of the thyroid involution (*th.*), at the junction of the hind brain (C^3.) with the myelon. The notochord (*nc.*) is very large, and has no investing cartilage on its sides. Considerable tracts of a pair of extra-branchials come into view in this section, which is only deficient by losing the bend at each shoulder and the lowest part of each bar in the region of the thyroid body (*th.*). This section shows well what a mere lateral figure (fig. 8) cannot so well, namely, the curious inflexion of the main band immediately behind the aperture; this, however, is clearly indicated in the figure of the transformed Lamprey's basket-work (Plate 18, fig. 1). This section shows that the junction of the main bar with the upper longitudinal band takes place close to the notochord, but is quite independent of it; where the shoulder is cut across (fig. 6), there the rod shows four cells, more or less overlapping each other. The other or upper end of the bar (fig. 6) must be considered as severed obliquely (see fig. 8), taking in both the longitudinal and the descending bar at once; the edge of the sectioned part passes a little into the interspace between the notochord and aorta (*nc.*, *ao.*).

If anything remains obscure after this description, I hope to make it plain in what follows, namely, an account of the cephalic and branchial skeleton of the fully-formed and full-sized larva or *Ammocœte*.

On the skeletal structure of large larvæ of Petromyzon fluviatilis.

In following these descriptions the reader is referred to the external figure also of the *Sand-pride* or Ammocœte (larva of *P. fluviatilis*, Plate 8, figs. 4–6).

A.—*Vertical section through head and branchial region of a larva* 6 *inches long.*

In this *diagrammatic figure* (Plate 25, fig. 10) we see the hooded pouch of the mouth (see also fig. 8, *m.*) formed by the upper lip (*u.lp.*), with its moss-like growth of *inner barbels* (*bb.*). Then there is the velum (*vl.*) separating the oral cavity (*stomadæum*) from the general pharyngeal space (fore part of *archenteron*); this velum, or right and left vertical curtain, is attached above under the fore part of the auditory capsule, and is, so to speak, a production of the inner edge of the hind part of the 1st visceral fold; and behind and external to it, in the re-entering angle between it and the cheek, is the rudimentary *non-perforate* 1st *cleft.*[*] Behind this part the seven branchial pouches (*br.p*^{1}.–*br.p*^{7}.) are laid open, and their main folds shown; behind them is the heart (*h.*); this section is just *beyond* the mid-line below, for it exposes the cavities of the pouches of the *right* side. Under the muscular segments we see the myelon (*my.*) in its theca, but the brain has been removed to show the auditory capsule (*au.*) and its meatus. In front of the capsule the trigeminal (V.) passes out, and behind it, the vagus (X.). In the middle of the space between the auditory capsule and nasal sac (*ol.*) the optic nerve (II.) escapes. There is only cartilage in the mid-line in front—the trabecular commissure or ethmoid (*eth.*); over it is the nasal sac (*ol.*) with its cartilaginous roof, and a pouch is growing downwards and backwards as the beginning of the "posterior nasal canal" (*p.n.c.*); the sac opens above as the external nasal aperture (*e.n.*). The notochord (*nc.*) bends downwards in front, and reaches to the pituitary region a little in front of the ear-capsules.

This sectional *plan* will enable us to understand what follows.

B.—*Dissected head of larval* P. fluviatilis, 6 *inches long.*

The *larva* is now eighteen times the length of the *embryos* just described, and that which strikes the eye at once is that the trabeculæ (Plate 19, figs. 4, 5) have united in front to form the rudimentary ethmoid, and that the cartilage is nearly all, in the cranium proper, of the hard kind—it has passed insensibly into this sort.

The cranium is now a long loop or *staple* of cartilage; the points of which, behind the ears, are soft, but the rest all hard cartilage. The fore end turns round by a sudden convexity (*eth.*), and the sides (*tr.*) are pushed in twice, first a little, where the optic nerves (II.) emerge, and then a second time, where they clamp the notochord (*nc.*) *near*, but not *at*, its narrow bluntly-pointed end. The lanceolate space thus enclosed is only properly *pituitary* just in front of the notochord, and under the greater, fore part, of this space a floor is formed, notched, behind, under which the posterior nasal canal is beginning to creep (see Plate 25, fig. 10, *ol., p.n.c.*). The lesser oval space, behind, lies lower than the front part of the proper membrano-cranium, and this hind part is the pituitary region. The under surface of the conjoined trabeculæ (Plate 19, fig 4, *tr.*) is convex, but above (fig. 5), the bars, in their fore half, are tilted, and the upper edge is growing into a low crest. This crest becomes the ethmoidal and orbito-sphenoidal walls (see Plate 19, fig. 1, *eth., o.s.*); it is not well seen except in ripe larvæ (Plate 19, fig. 5); in younger specimens (Plate 26, figs. 5, 6) there is merely a tilting of the bars which have a concave upper edge.

These rudiments of cranial walls are not seen in the alisphenoidal region, here the *walls* are entirely membranous before transformation. In the parachordal region

---

[*] Professor HUXLEY (Proc. Roy. Soc., Vol. xxiii. (1874), p. 129) speaks of an external opening to this cleft, but neither BALFOUR, SCOTT, nor I can find it.

(*iv.*) the notochord is exposed both above and below, and rapidly enlarging, carries the attenuated bars at their soft ends far out from the mid-line.

Beneath the meatus auditorius internus each parachordal (fig. 4, *iv.*) gives off a small wing or flap which is continuous with the middle of the infero-internal face of the capsule (*au.*); fore and aft of these flaps there is a considerable chink, or *foramen lacerum*, over which the large ganglionic masses of the *pre*- and *post*-auditory nerves (V., X.) lie.

The chinks in front of the flaps are bounded by the outgoing *pterygo-pedicle* (*pd.*, *pg.*). This is, now, a notable narrow wing of hard cartilage, right and left, with a broad proximal part, a dilated sub-bilobate terminal part growing forwards and downwards, and a narrow arcuate stalk.

Compared with the recently transformed skull (same Plate, figs. 1–3), we see that this is the pedicle, with the pterygoid region *free*, as in a Salamandrian, but with a small bud of the future epi-hyal growing from its fore lobe, behind.

The olfactory roof (*na.*) is a broad semicircular plate, convex above and concave below, and with the external aperture (*e.n.*) in the round notch; it is composed of soft cartilage.

The auditory sacs (*au.*) are reniform with the *hilus* opening as the meatus internus; they are somewhat pinched in on both sides, but most on the inner, and their long axis is parallel with that of the skull; as before mentioned, they are fastened to the basal plate by a band of cartilage, right and left—the sub-auditory wings of the parachordals (*iv.*). The capsule has a small perforation under the Gasserian ganglion (fig. 4, *au.*, V.).

C.—*Dissection of a large larva of* P. fluviatilis, *showing the branchial basket-work.*

The preparation here figured (Plate 25, fig. 8) had the superficial parts moved from the branchial region, so as to show the whole basket-work of one side, and the heart. If this figure be compared with that showing the same parts in the young of *P. marinus* (Plate 18, fig. 1) we shall see the changes produced by metamorphosis in this part. Here there is no extra-hyal,[*] and no extra-pericardial skeleton, but seven sinuously-vertical bars, each passing behind a cleft or external branchial passage, and each united to its fellow, before and behind, by four longitudinal tracts. The whole structure is composed of soft cartilage, now much more consistent, and with larger cells, than in the embryo. The cartilage is of a peculiarly light and spongy kind, much like that described by me some years ago in the Tadpole of *Dactylethra*.

The *cervicorn* outgrowths seen in the transformed young are not present; the upper connecting band is nearly straight, the lower is formed of a series of small arches, and these are placed right and left, back to back (Plate 25, fig. 9).

The principal bends of the main arches are, *inwards*, behind each aperture, and

---

[*] The loop of cartilage round the 1st gill-opening is lettered *ex.hy.* by mistake.

forwards, above and below it. The first bar encloses its aperture by a simple loop of cartilage; in the skin in front of this loop we see the fore end of the *branchial groove*, in which place I have, many a time, searched in vain for the 1*st cleft*, the hyomandibular; the first open passage is the hyobranchial, and thus the fore half of the first branchial pouch must be accredited to the hyoid region. In the Tadpole the hyoid has no gill, and its three clefts answer to the second, third, and fourth of the Lamprey; the former has *three* pouches, *four* extra-branchials, and *four* rudimentary cerato-branchials inside, which form an imperfect fringed floor or septum between the food-pharynx and the respiratory cavities (see Phil. Trans., 1881, Plate 1, fig. 4).

D.—*Vertically-transverse sections of the head and branchial region of a large (but not ripe) larva of* P. fluviatilis.

1*st Section* (Plate 19, fig. 6).—The first of these sections (see also Plate 8, figs. 4–6) is through the external nasal opening (*e.n.*), and the upper lip (*u.lp.*) with its undergrowth of mass-like barbels (*bb.*); the lips are of great depth, and the top of the face is concave.

2*nd Section* (Plate 19, fig. 7).—In this the nasal roof (*na.*) is cut across behind the opening. The top of the face is still more concave than in the last, and the whole section is deeper.

3*rd Section* (Plate 26, fig. 1).—The roof (*na.*) of the nasal capsule is cut through here so as to miss the median part. The capsule is more vertical than could be shown in the dissections (Plate 19, figs. 4, 5, *na.*), and the bilobate organ of smell (*ol.*) is laid bare; the other parts are similar to what is seen in the last.

4*th Section* (partial; Plate 26, fig. 2).—Here the hinder angles of the capsule (*na.*) are cut across, and the olfactory lobes (C^{1b}.) are seen in section; barbels are still seen under the hood-like upper lip. The fore part of the nasal canal (*p.n.c.*) is shown.

5*th Section* (partial; Plate 26, fig. 3).—This is very similar to the last, but further back: this shows the angles of the nasal cartilage (*na.*) for the last time, and the large olfactory crura (C^{1b}.) are cut across their middle.

6*th Section* (partial; Plate 26, fig. 4).—The fore brain (C^{1}.) and pineal body (*pnl.*) are here severed, and the skull in its front region; the section is through the fore part of the ethmoid (*eth.*), behind the nasal sacs; the barbels (*bb.*) of the upper lip (*u.lp.*) are becoming folds. The proximal part of the posterior nasal canal (*p.n.c.*) is circular at this point.

7*th Section* (partial; Plate 26, fig. 5).—This is close behind the last, and shows the fore part of the cranial trough formed by the ethmoidal commissure of the trabeculæ. The posterior nasal canal (*p.n.c.*) is now crescentic in section, with the concavity above.

8*th Section* (Plate 26, fig. 6).—Here the fore brain (C^{1}.) rests upon the trabeculæ (*tr.*), now distinct, but tilted, ready to begin the side walls of the skull in the ethmo-presphenoidal region. The hinder blind end of the budding "posterior nasal canal" (*p.n.c.*) is cut across; in fig. 6^a, (36 diams.), the lining of this pouch is shown to be composed of round cells.

9th Section (partial; Plate 26, fig. 7).—This section is through the fore brain (C^1.), and the fore part of the eye-balls (*e.*). The trabeculæ (*tr.*) are now short-oval in section, and are tilted inwards, above.

10th Section (partial; Plate 26, fig. 8).—This is through the middle of the eye-balls (*e.*), and is quite similar to the last.

11th Section (partial; Plate 26, fig. 9).—This is through the mid brain (C^2.), the back of the eye-balls (*e.*), the fore part of the Gasserian ganglia (V.) and of the notochord (*nc.*). Here the trabeculæ (*tr.*) are sharp above, and inturned; they are a considerable distance from the apex of the notochord (see Plate 19, figs. 4, 5).

12th Section (partial; Plate 26, fig. 10).—This is the first section through the hind brain (C^3.); it also passes through the fore part of the auditory capsules (*au.*), just behind their front face. There is here a rudiment of the alisphenoidal wall cresting the capsules on the inside, and their inner wall is complete, as this is in front of the "meatus;" externally, part of the shell of the fore face of the capsule is drawn. The cartilages (*iv.*) now approach the notochord (*nc.*), and they are winged at this point; the wings are the *pterygo-pedicles* (*pd.*, *pg.*), which arch gently over the buccal cavity and thicken, externally.

13th Section (partial; Plate 23, fig. 8).—Here we lose the alisphenoidal crest, and the transverse facial outgrowths; the inner wall of the capsule (*au.*) is still perfect; the basal plates or parachordals (*iv.*) are oval in section.

14th Section (partial; Plate 23, fig. 9).—This is through the *meatus internus* or internal auditory fenestra through which the 8th nerve passes. It also shows the partial junction of the capsules with the parachordals (*au.*,*iv.*); those bands are now of a considerable height, and are nearer the enlarging notochord (*nc.*).

15th Section (Plate 26, fig. 11).—By comparing this section with the dissected skull (Plate 19, figs. 4, 5) and basket-work (Plate 25, fig. 8), everything skeletal can be identified. It is close to the back of the head, the ganglia of the vagus (X.) are cut through, and also the narrow tracts of the basal plates (*iv.*) lying against the large notochord (*nc.*); the hind brain (C^3.) still comes into view. This shows the 1st branchial pouch ($br.p^1$.) in simple outline—the 1st branchial opening (*e.b.a.*) and the loop of cartilage (*ex.br.*) enclosing it in front of the 1st extra-branchial.

We are now in the front region of the "archenteron," which is a generalised pharynx (*phx.*) permitting the passage of both the food and of the water currents into the pouches.

16th Section (Plate 26, fig. 12.)—This is through the back part of the 1st branchial pouch and the extreme end of the hind brain (C^3.). There is no parachordal cartilage at this part, and the top of the 1st extra-branchial arch (*ex.br.*)

is shown on each side; the sinuosities of the bar cause it to be severed at many points,—*six* on each side. The enclosing bars, and the inbent form of the main bar behind the aperture, are well seen.

17*th Section* (Plate 26, fig. 13).—This is through the forepart of the myelon (*my.*), a curiously flat structure, convex above and concave below. This, which may be through the second or third pair of pouches, shows the thyroid body (*th.*) below. Under it the lower part of an extra-branchial (*ex.br.*) is cut across, and at the apertures the cross bars and part of the inbent main bar is seen. The theca vertebralis is much larger than is necessary for the myelon (*my.*), but it is not much greater in diameter than the notochord (*nc.*), with its thick membranous sheath. Under it we see the aorta (*ao.*), and outside it other large vessels.

Summary and Conclusion.

The remarks now to be made must be considered to be a continuation (with some repetition) of those given at the end of my Ist Part.

These Fishes appear to have been given up in despair by most recent Anatomists, and yet JOHANN MÜLLER laid a solid foundation for all his successors to build upon. Anyone may be proud to become a continuator of, and a commentator on, that great and almost unerring observer.

A continuator and a commentator worthy of him has, from time to time, thrown light upon these types. I refer, of course, to Professor HUXLEY, whose researches, however, needed, what they have now to a great degree obtained, namely, the corroborating and also the correcting light derived from Embrology. Following in the footsteps of the lamented CALBERLA, Mr. W. B. SCOTT has done, and is still doing, excellent work in this way, but (before our great loss) Professor F. M. BALFOUR had shed most welcome light upon this subject.

The problem of the morphology of this group has been to me for years an irritating opprobrium, on account of its apparent insolubility; and I have again and again made advances upon it, sideways, or crabwise, fresh from the contemplation of more normal types. Those *Ichthyopsida* that undergo metamorphoses after hatching, and thus have a *larval stage* during a longer or a shorter time, are of the most service in this matter. Hence I infer that the Marsipobranchs belong to a low grade, and that even supposing the Myxinoids to be degenerate descendants of some more developed form, yet I feel quite certain that such an *archaic non-degenerate Myxinoid* would lie far below our known existing Fishes, such as the Elasmobranchs, Ganoids, and Teleosteans. But the three groups just mentioned lie far out of the way of the Marsipobranchs. The early stages of the *Anurous Batrachia* give us the best clue to them, and far off as they are from them, they are indeed their nearest existing relatives. What the early stages of the "Chimæroids" and "Dipnoi" would show, it is impossible to say; unfortunately, their early stages are not known.* With regard to the question as to what a truly Archaic Vertebrate would be like, I feel confident that the early stages of a Myxinoid would yield us the most trustworthy evidence. Those Fishes (*Myxine* and *Bdellostoma*) are not, even in their adult condition, Vertebrata, if we speak by the letter. They are mere "*Craniate Chordata*," for, throughout life, they, like the temporary *Ammocœte*, or larval Lamprey, show no traces of cartilage in their *spinal region*, although they have a solid, complex, generalised, but rudimentary cranium. It is easy to see that the Ammocœtine form of Fish is the platform, so to speak, on which both the Myxinoids and Petromyzoids are built, and although the former rise to a lesser height above that platform, yet they do undergo a large amount of metamorphosis and are marvellously specialised in their own peculiar way. So true is this, that in the burden now, at last, laid upon me, namely, the interpretation of the Mammalian skull and the searching out the pattern of the *Prototheria* or primary Mammalia (and, if the thing be possible, getting some light upon their ancestors, the imagined *Hypotheria*), I know of no types among the *Ichthyopsida* so likely to help me in this dark work as these same Myxinoids.*

---

* See Note to p. 411.

This we may say, namely, that the Myxinoids, Petromyzoids, and Tailless Amphibia, are three groups more nearly related to each other than to any known *Ichthyopsida*, and yet are far apart, in reality.

Roughly speaking, in spite of the gap made by the extinction of possibly many hundreds of *genera*, the adult Myxinoid may be said to represent a larval Petromyzoid, and the adult Petromyzoid a larval Batrachian (Frog or Toad). Indeed, these three groups might be studied in their special structure and in their structural relations to each other without the other *Ichthyopsida* once coming into mind. A knowledge of the latter does, indeed, help in this business, but they lie far out of the way, and have a specialisation and a *finish* in their structure for which we look in vain in the *permanent* and *temporary* Marsipobranchs.

Even the *Chimœroids* come so near the ordinary Elasmobranchs as to suggest that their embryology would not be so helpful as one might imagine, especially if their solid upper face has been acquired as a *secondary* modification and not a *primary* condition such as we see in the Tadpole, which is especially solid and largely continuous with the basis cranii, in the larval Aglossal types, *Dactylethra* and *Pipa.*†

Sharks, not *Skates*, retain *remnants* of the bars of the extra-branchial basket-work of the Lamprey; Tadpoles show *rudiments* of the intra-branchial arches of Sharks and Skates. By far the most generalised condition of the branchial skeleton is seen in the Tadpole of the Aglossal *Dactylethra*, and the cartilage of which it is composed is similar to that of the embryo Lamprey, 7 or 8 millims. in length. In that type and in the other Aglossal form, *Pipa*, the membranous space between the *palato-quadrate arcade* and the *trabecula* is almost absent. Yet in these, as in all the Anura, there is in the 1st visceral arch a cerato-branchial element, a free Meckelian (mandibular) cartilage. Professor HUXLEY and I agree in thinking that we have found a true mandibular rudiment in the Lamprey after transformation; certainly there is none in the Myxinoids; and the *quadrate region* (*and condyle*) is quite suppressed in both the types of the Marsipobranchs (Myxinoids and Petromyzoids). Moreover, the place where this tract *should* be, is not where we find it in the larval condition of the Frog or Toad, namely, at the fore part of the face; but under the exit of the 5th nerve, where we find it in transforming Tadpoles, whose tail has become a mere stump.

---

* The reader will see that I am thinking of Professor Huxley's masterly paper—"On the Application of the Laws of Evolution to the arrangement of the Vertebrata, and more particularly of the Mammalia" (Proc. Zool. Soc., 1880, pp. 649–662). The author of that paper has unconsciously set the writer his work for some years to come; the "one thing" for him is to become the *continuator* of, and *commentator* upon, him who made that daring outline.

† The interposition of those remarkable Sharks, *Cestracion* and *Notidanus*, between the ordinary kinds and the Chimœroids, makes the likelihood of the solidity of the upper jaw being *primary* a very doubtful thing; I once thought otherwise, but found Mr. Balfour strongly set against me in this suggestion.

This is easily accounted for; in the Tadpole the small divided suctorial (lower labial) cartilage is carried by the mandibles—it is fixed between them; these are its *arms*. During transformation, the lower lip of the Lamprey shoots forwards, and instead of lying back, as it did, under the hood-like upper lip, grows to the forefront, and has the upper lip merely lying on the top of its upper rim in front; thus this production of the *post-oral* lip becomes the foremost part of the head.

Hence anything corresponding to mandibles in the Lamprey are carried far away from their *pier* or "suspensorium;" thus the hinge part of that pier is suppressed. The labials of the Lamprey correspond to the *temporary* labials of a Tadpole; the cartilages that appear in that region (above), during transformation, correspond to what is seen in the upper fore-face of a Shark or Skate.

The palato-quadrate arcade, with no *quadrate lobe*, and the distal cartilages attached to the suctorial disk, are all that can be accredited to the 1st visceral arch of the Lamprey. Its 2nd has no "pharyngo-hyal" element, but the lower part grows directly out of the back of the arrested suspensorium (part of the 1st arch); yet the lateral, sub-distal, and basal parts are well developed as the lingual skeleton. The only rudiment of an *intra*-branchial, behind the hyoid, is the hinder part of the large continuous basal bar ("lingual cartilage"); all the rest is *extra-visceral*, and after transformation the hyoid arch acquires an outer band of this nature. How the Myxinoids differ in these respects I have already shown, but their *intra*-visceral basket-work is dissociated from their branchial pouches, which are carried far back under the spine. Then, in their mouth, not circularly suctorial, as in the Lamprey, the dental armature, and its *special buccal skeleton*, is a huge development of parts, the like of which are feeble and subsidiary in the Lamprey.

The Myxinoids do transform beyond the Ammocœtine stage, but they appear to have suffered some deflection during the process, and to have been stopped in their attempts to rise to a higher platform; yet, full of metamorphic force, they have spent their energy on the old low level; they are, as it were, highly modified Ammocœtes, doomed to much morphological arrest, and to some degree of degradation of parts, once promising a higher development.

A study of their development will show whether these suggestions are true or untrue.

LIST OF ABBREVIATIONS.

N.B.—Many of the abbreviations are the same as in Part I.; the following are additional.

ao.	Aorta.	*l.lp.*	Lower lip.
al.s.	Alisphenoid.	*l.t.*	Lingual (and labial) teeth.
b.p.	Buccal pouch.	*m.d.m.*	Median distal mandibular.
br.a.	Branchial artery.	*n.a.* (and *v.a.*)	Neural (or vertebral) arch.
br.c.	Branchial canal.	*or.m.*	Orbital muscles.
br.p′.	Branchial folds.	*o.s.*	Orbito-sphenoid.
c.tr.	Cornu trabeculæ.	*o.s.f.*	Orbito-sphenoidal fenestra.
e.ba.	External branchial aperture.	*py.*	Pituitary space.
ex.br.	Extra-branchial.	*s.d.*	Sucking disk.
ex.hy.	Extra-hyal.	*tg.*	Tongue.
i.b.a.	Internal branchial opening.	*th.*	Thyroid body.
i.v.s.	Intervelar shelf.	*u.l.*	Upper labial.
l.d.m.	Lateral distal mandibular.	*u.lp.*	Upper lip.
l.l.	Lower labial.	*v.a.* (and *n.a.*)	Vertebral (or neural) arch.

DESCRIPTION OF THE PLATES.

Plate.	Fig.		Number of times magnified.
18	1	*Petromyzon marinus;* one-third grown; cranio-branchial skeleton; side view	$3\frac{1}{5}$
,,	2	The same; lower view	$3\frac{1}{5}$
,,	3	Fore part of same; upper view	$3\frac{1}{5}$
,,	4	The same; lower view	$3\frac{1}{5}$
,,	5	Vertical section of the same object	$3\frac{1}{5}$
,,	6	Lingual cartilage of the same specimen; lower view	$6\frac{2}{5}$
,,	7	The same; upper view	$6\frac{2}{5}$
,,	8	Part of the same; side view	$6\frac{2}{5}$
19	1	*Petromyzon marinus;* recently metamorphosed (5 inches long); skull; upper view	12
,,	2	The same; lower view	12
,,	3	The same (section); inner view	12
,,	4	*Petromyzon fluviatilis;* large larva (6 inches long); skull; lower view	15
,,	5	The same; upper view	15
,,	6	*P. fluviatilis;* a younger larva, but of nearly the same size; *first* of a series of vertically-transverse sections through fore part	12
,,	7	The same; *second* section	12
20	1	*Petromyzon fluviatilis* (adult); *first* of a series of vertically-transverse, thin, transparent sections	5
,,	2	The same; *second* section	5
,,	3	The same; *third* section	5
,,	4	The same; *fourth* section	5
,,	5	The same; *fifth* section	5
,,	6	The same; *sixth* section	5
,,	7	The same; *seventh* section	5
,,	8	The same; *eighth* section	5
,,	9	The same; *ninth* section	5
,,	10	The same; *tenth* section	5
,,	11	The same; *eleventh* section	5
,,	12	The same; *twelfth* section	5

Plate.	Fig.		Number of times magnified.
21	..	(*As in last Plate.*)	
,,	1	The same; *thirteenth* section	5
,,	2	The same; *fourteenth* section	5
,,	3	The same; *fifteenth* section.	5
,,	4	The same; *sixteenth* section	5
,,	5	The same; *seventeeth* section	5
,,	6	The same; *eighteenth* section	5
,,	7	The same; *nineteenth* section	5
,,	8	The same; *twentieth* section	5
,,	9	The same; *twenty-first* section.	5
22	..	(*As in last Plate.*)	
,,	1	The same; *twenty-second* section	5
,,	2	The same; *twenty-third* section	5
,,	3	The same; *twenty-fourth* section	5
,,	4	The same; *twenty-fifth* section	5
,,	5	The same; *twenty-sixth* section	5
,,	6	The same; *twenty-seventh* section	5
,,	7	The same; *twenty-eighth* section	5
,,	8	The same; *twenty-ninth* section	5
,,	9	The same; *thirtieth* section.	5
23	1	*Petromyzon fluviatilis* (adult); solid vertical section of fore part	2½
,,	2	The same; solid horizontal section of head.	2½
,,	3	The same; another similar section made on a higher plane	2½
,,	4	*Thirty-first thin* section (as in Plates 20–22)	5
,,	5	*First* similar solid section of a larger specimen	3
,,	6	The same; *second* section	3
,,	7	The same; *third* section.	3
,,	8	*Petromyzon fluviatilis* (larva, 6 inches long); *thirteenth* section (as in Plate 26)	12
,,	9	The same; *fourteenth* section	12

Plate.	Fig.		Number of times magnified.
24	1	*Petromyzon planeri* (embryo, 9·5 millims. long); *first* of a series of vertically-transverse sections of cephalic and branchial regions	150
,,	1A	Part of a similar section of an embryo 7·8 millims. long	300
,,	2	*Second* section of larger embryo	150
,,	2A	A similar section of smaller embryo	300
,,	3	*Third* section of larger embryo	150
,,	4	The same; *fourth* section	150
,,	5	The same; *fifth* section	150
,,	6	The same; *sixth* section	150
,,	7	The same; *seventh* section	150
,,	8	The same; *eighth* section	150
,,	9	The same; *ninth* section	150
25	..	(*Partly as in last Plate.*)	
,,	1	Part of the same section as in Plate 24, fig. 5. . . .	300
,,	2	Another partial section from the same series between figs. 5 and 6 of Plate 24	300
,,	3	Another partial section between figs. 7 and 8 of Plate 24	300
,,	4	A similar section near fig. 9, Plate 24	300
,,	5	Same series; a complete section through branchial region and thyroid body	150
,,	6	Part of last section	300
,,	7	Skull of smaller embryo (7·8 millims. long) of *P. planeri*; lower view	150
,,	8	*Petromyzon fluviatilis* (larva, 6 inches long); dissection of branchial region; side view	5
,,	9	Part of same; lower view	5
,,	10	The same; vertical solid section of head and branchial region	5

Plate.	Fig.		Number of times magnified.
26	..	*Petromyzon fluviatilis* (larva, 6 inches long)	
,,	1	*Third* of a series of thin vertically-transverse sections through head and branchial region	12
,,	2	The same ; *fourth* section	12
,,	3	The same ; *fifth* section	12
,,	4	The same ; *sixth* section	12
,,	5	The same ; *seventh* section	12
,,	6	The same ; *eighth* section	12
,,	7	The same ; *ninth* section.	12
,,	8	The same ; *tenth* section.	12
,,	9	The same ; *eleventh* section	12
,,	10	The same ; *twelfth* section	12
,,	11	The same ; *fifteenth* section.	12
,,	12	The same ; *sixteenth* section	12
,,	13	The same ; *seventeenth* section	12

XI. *On the Organization of the Fossil Plants of the Coal-Measures.*—Part XII.

By W. C. Williamson, *LL.D., F.R.S., Professor of Botany in the Victoria University, Manchester.*

Received May 4,—Read May 11, 1882.

[Plates 27–34.]

In Part IX. of this series of memoirs (Phil. Trans., Part II., 1878, pp. 319–322) I described, under the generic name of *Astromyelon*, a series of stems, transverse sections of which might readily be, and for some time were, mistaken for sections of Calamites; but I pointed out the differences which separate widely these two types of stem. Attention was directed to the almost universally decorticated condition in which the *Astromyelons* were found; the only exceptions being one or two examples (*loc. cit.*, Plate 19, fig. 7, *d*), in which the vascular zone was surrounded by a thin cellular layer.

At the recent meeting of the British Association at York, Mr. Cash, of Halifax, and Mr. Hick, of Harrogate, described a remarkable stem, discovered by Mr. Binns in the Halifax beds, and to which they gave the name of *Myriophylloides Williamsonis.** I shortly afterwards suggested the desirableness of substituting the generic name of *Helophyton* as preferable to that of *Myriophylloides*, for reasons given in the note in which this suggestion was made.†

I subsequently received a letter from Mr. Spencer, of Halifax, telling me that he had obtained additional specimens of the new plant, which convinced him that it was a corticated state of the Oldham *Astromyelon* which I had previously described. All the specimens discovered up to the present time having been placed in my hands by my excellent auxiliaries, and undergone a careful investigation, I have no doubt about the correctness of Mr. Spencer's conclusion.

The plant proves to be a much more varied and remarkable one than I had previously thought.

The simplest form in which it has hitherto been met with is represented in fig. 1. This specimen, which is black and carbonised, is a transverse section of an axis which differs very widely from the ordinary forms of the Oldham *Astromyelon*. In its centre,

---

* This interesting communication has since been published in the Proceedings of the Yorkshire Geological and Polytechnic Society, vol. vii., part iv., p. 400, 1881.

† 'Nature,' Dec. 8, 1881, p. 124.

a, we have a somewhat confused admixture of cells and vessels, constituting a central axis, surrounded by an inner cortical zone, *b*, of radially compressed cells, arranged in an approach to regular circles, and passing outwards into a less regularly disposed series of much larger cells, *c*. From these latter, isolated lines of cells, *d*, radiate, chiefly in single rows, like the spokes of a wheel. The nave of this wheel is composed of a thick zone, *e*, of large and irregular parenchymatous cells. The drawing is enlarged 70 diameters—the maximum diameter of the section being about ·08 of an inch.

Fig. 2 represents the transverse section described by Messrs. Cash and Hick at York, enlarged 55 diameters. It presents very different features from those of fig. 1 so far as its central portion is concerned. At *a* we have a large medulla, about ·04 of an inch in diameter, composed of very regular parenchyma, and closely resembling that of the Oldham *Astromyelons*. The central cells are much larger than the peripheral ones, some of them being ·005 in diameter. This medulla is surrounded by narrow, imperfectly developed, and somewhat irregular zone of vessels, *b*, arranged in radiating lines. The concentric disposition of the cells of the innermost bark, *c*, is well shown in this section, as are the radiating lines of cells, *d*, connecting this inner bark with the peripheral parenchyma *e*. Though these lines of cells have been somewhat disarranged by external pressure, we have no difficulty in tracing a continuous zone of them from *d′* to *d″*.

Fig. 3 represents a very important section for which I am indebted to Mr. Spencer: important because it demonstrates the identity of my *Astromyelon* and the *Myriophylloides* of Cash and Hicks in the most decisive manner. In my description of the former plant I directed attention to some features very characteristic of it. The chief of these was the distinct outline and peculiar form of the conspicuous vascular wedges constituting the exogenous zone (*loc. cit.*, Plate 19, fig. 1, *b*), and the relations of these wedges to the large medulla which that zone enclosed. The laminæ of each wedge, *b*, converge at their medullary extremity, where there exists small groups of what, in my previous memoir, I designated "a few vessels of somewhat larger size than those composing the rest of the vascular zone" (*loc. cit.*, p. 320). I cannot quite satisfy myself whether these are actually vessels or liquified cells.* In either case they bear a definite relationship to the vascular wedges with which each of the several small clusters of them is associated. In fig. 3 the characteristic medulla is conspicuous at *a*. The clusters of cells or vessels just referred to are seen at *a′*, and the distinctive forms of the vascular wedges are not difficult to trace, as is shown at *b*. The exogenous zone has undergone a much greater development in this specimen than in fig. 2. The identity of the plant with the *Myriophylloides* of Cash and Hicks is shown by the retention of a small portion of the cortex. The innermost layer is imperfectly retained at *c*, but the radiating cellular laminæ are sufficiently distinct at *d*, terminating in the outer layer of cortical cells at *e*.

---

* I have since obtained absolute proof that these are really vessels which may be regarded as constituting a medullary sheath.—July 6th, 1883.

Fig. 4 represents a section for which I am indebted to Messrs. CASH and HICKS. Virtually a vertical one, it has passed obliquely through the outer cortical parenchyma at its upper part and traversed the medulla at its lower end. The medullary cells are seen at *a*, corresponding closely with those represented by fig. 3, *a*, in Plate 19 of my Memoir IX.* The vessels of the exogenous zone are traversed almost radially at *b*, and more tangentially at *b'*. We next have the long, narrow, square-ended cells of the innermost bark at *c*. Above this tissue we obtain double light respecting the structure of the spokes of our vegetable wheel seen in the transverse sections. We learn that these radiating lines of cells are merely the transverse sections of long, vertical, cellular, radiating laminæ, *d*, which separate large intercellular lacunæ, *d''*, whilst at *d'*, *d'* we learn that the constituents of these laminæ are very regularly disposed cells elongated radially and having a mural arrangement. The cells of the outer cortical parenchyma, *e*, present no special peculiarities. The only additional feature noticeable in this section is a small bundle of vessels passing laterally outwards at *f*.

The three sections last described manifestly belong to the same plant in different stages of development; but I have now to direct attention to another series of specimens in my cabinet, some of which were first discovered by Mr. SPENCER, but to which others have been added by Mr. BINNS. So far as their cortical structures are concerned they are absolutely identical with those already described. Thus in each of the transverse sections, figs. 5 and 6, we have the inner cortical layer at *c*, the radiating laminæ at *d* enclosing the lacunæ at *d''*, and the outer cortex at *e*. The differences are seen in the structure of the vasculo-medullary axis—and especially of its central portion. This appears in both the sections figured to be largely if not entirely vascular, and others in my cabinet exhibit the same characteristic aspect. The exogenous vascular zone, *b*, also exhibits much less definitely the grouping of the radiating vascular laminæ into distinct wedges than is the case with the section, fig. 3. At the same time we fail to discover that grouping even in fig. 2, though the section there represented possesses the large cellular medulla so characteristic of fig. 3. In fig. 6 we find the lacunæ and radiating cellular laminæ replaced at *d'''* by a mass of coarse cellular parenchyma, and from which a vascular bundle is seen emerging at *f*.

Fig. 7 is an instructive section for which I am indebted to Mr. SPENCER. It appears to combine features seen in figs. 5 and 6 with others seen in fig. 1, and is further valuable since it illustrates the strong tendency to develop branches which seems to characterise this plant.

At the upper extremity, A, of the figure we have a nearly transverse section of an axis which has corresponded closely with fig. 1. At *a* we have an axial cluster of vessels, not arranged in any regular order, or surrounded by an exogenous zone. At *c* are the narrow elongated cells of the innermost cortex, intersected obliquely, whilst the radiating cellular laminæ are seen at d enclosing the large lacunæ at d''; these, in turn, being invested by the thick outermost parenchymatous cortex, e.

---

* I may add that I have a true vertical section of another specimen of the new plant which is almost a facsimile of the main axis of fig. 2 in Plate 19 of my ninth memoir already referred to.

At the opposite end, B, of the section we find another branch, intersected very obliquely, and which is evidently tending outwards, in opposite directions. We here discover a central vascular axis, a, dividing dichotomously into a larger one, a', and a smaller one, a''. These branches are successively surrounded by the inner bark, c, the radiating laminæ, d, with their enclosed lacunæ, d'', and the outermost cortex, e. At C a yet smaller vascular bundle, a''', is passing laterally outwards. We thus have four branches passing in as many separate directions in this one specimen. None of these branches display any indication of a distinct central medulla, though cells appear to intermingle with the irregularly grouped vessels at A, a. It is thus clear that this section belongs to a plant in which, as in fig. 1, we have axial vascular bundles unsurrounded by an exogenous zone, whilst in figs. 5 and 6 we have the same plant in which such a zone is fully developed.

The vessels of the vascular bundles present some peculiarities, examples of which are represented in figs. 8–14. In describing the Oldham *Astromyelon* in my memoir, Part IX., I mentioned the extreme indistinctness if not almost entire absence of all traces of structure in the walls of these vessels, though in some few there were suggestions that they had been barred. The Halifax specimens differ from the Oldham ones in this respect, though there is room for doubting whether or not the latter shows fully their original nature. In all the figures, from 8 to 13 inclusive, a considerable, and often by far the greatest, part of the walls of the vessels are homogeneous and structureless. Thus in fig. 8 we have a single vertical series of small translucent, slightly oval, areolæ, the longer axes of which cross the vessel somewhat obliquely. In fig. 11 we have a similar arrangement, only the areoles are still more oblique, and more elongated transversely. In fig. 9 the areolæ are still small but almost circular. In fig. 10 the areolæ are more irregular both in size and number, but they still occupy the central area of the vessel. In fig. 12 the larger vessel approaches more nearly to an ordinary reticulated modification of the scalariform type of vessel, whilst in the smaller one the areolæ are larger in proportion to the diameter of the vessel than in most of the other examples, but in both the striking obliquity of the areolæ, seen in figs. 8 and 11, is again observable. The forms here described are those which characterise all the specimens figured, as well as others in my cabinet, except fig. 7; the vessels in the branching vascular bundle, B, a, of that section resemble figs. 13 and 14, which approach nearer to the barred type ordinarily met with amongst the fossil plants of the Coal-measures; but even fig. 14 lacks the extreme regularity which ordinarily characterises these barred forms. Do these figures represent the actual state of these vessels when living, or has mineralisation destroyed the details of the structure of their walls save along certain lines? Such specimens as figs. 8, 9, and 11 are so peculiar that I incline to adopt the former explanation, and the more so because at some future period I shall have to call attention to some similarly remarkable vascular tissues which prevail in the mineral charcoals so abundant in the coals of the Carboniferous rocks.

All the specimens now described are from the Halifax beds; but I have received from Mr. BUTTERWORTH a specimen from Oldham in which the bark, though in a very imperfect state, presents the essential features of the Halifax examples.

The above descriptions show that we either have one very variable plant characterised by a bark in the middle of which are numerous large lacunæ, separated from one another by vertical radiating cellular laminæ, or that we have two or more distinct plants which have the same peculiar form of bark, but which differ in the organization of their central vasculo-cellular axes. I am inclined to regard the former of these alternatives as affording the true interpretation of these specimens. I think there can be no doubt respecting one conclusion suggested by the peculiar structure of the bark, viz.: that it indicates a plant of more or less aquatic habits. A similar structure is found in several flowering plants such as *Myriophyllum* and the petioles of *Aponongeton*. It reappears in the *Marsileæ* and *Pilularia*, amongst Rhizocarps, and it is not essentially dissimilar from that of the living Equisetums. That the plant was a Phanerogam is most improbable. It differs alike from the recent Equisetums and the fossil Calamites in the entire absence of nodal joints and medullary phragmata. The question suggests itself, may it possibly be a representative of the Marsileaceæ?

I have examined many living species of *Marsilea*, and find that on making transverse sections of their rhizomes, not too far from their growing tips, we obtain results not dissimilar from those seen in fig. 7. We constantly obtain three different, but organically united, sections. One of these is that of the main stem, in which a horseshoe-shaped vascular bundle approaches so nearly to a perfect circle as almost to enclose a central cellular axis. Another is that of the base of a leaf-petiole. In this the fibrovascular bundle is V-shaped, as in the secondary petioles of so many ferns. The third is a root-section in which the vascular bundle is central, and enclosed within those circular zones of cortical cells that are so common in the root-structures of Cryptogams. The existence of three such dissimilar structures in one section of a stem suggests the possibility of a similar explanation being applicable to the plant under consideration. The absence of the exogenous zone from the recent *Marsileæ*, whilst it is conspicuously present in our fossil, does not militate against my suggestion, since in this, as well as in other features, the *Astromyelon Williamsonis* does not diverge more widely from the living *Marsileæ* than the arborescent Lycopods of the Coal-measures do from their dwarfed living representatives, or than the Equisetums do from the Calamites.

Fig. 15 represents a section of a small organism from Halifax, ·02 of an inch in diameter, for which I am indebted to Mr. SPENCER. It may possibly belong to the plant just described, but this is doubtful. It consists of a central area, which is divided by a crucial arrangement of cells, *a*, into four lacunæ, *b*. The rest of the organism consists of a mass of parenchymatous disarranged cells of various shapes and sizes, many of which are filled with black carbonaceous matter, *c*. I can detect no vessels in the section. The division of the central portion into four lacunar cavities reminds us of the similar divisions in the leaves of *Isoetes*.

Psaronius Renaultii.

In my memoir, Part VII., pp. 10–13, I described, under the above name, some sections which I believed to belong to an arborescent fern, and in fig. 22**, *d*, I represented the only trace of a vascular bundle hitherto met with belonging to this plant. Mr. GEORGE WILD, of the Bardsley Collieries, Ashton-under-Lyne, has since furnished me with a much finer specimen, a section of which is represented in fig. 16. The vascular bundle, *a*, is quite perfect, and corresponds both in shape and size with several of those represented by CORDA, whilst the fragments of a second similar bundle at *a′* show that the section is but a portion of a large stem in which there has been at least one circle of similar bundles. Each of these vascular zones is enclosed within a thin phlœm sheath, *b*, whilst the fundamental tissue exhibits the small gum-canals, *c*, already described; some of these, *c′*, are filled with carbonaceous matter. The size of the bundle at its greatest diameter is 1·1, the figure being enlarged about 2½ times.

Zygosporites.

In my memoir, Parts IX. and X., I described some minute objects under the above name, and whilst recognising their striking resemblance to the zygospores of several Desmideæ, I declined to follow some of my French friends who regarded them as being true Desmids. A discovery by Mr. SPENCER in the Halifax beds has justified my doing so.

Fig. 17 represents an oblong sporangium containing several of these *Zygosporites* under conditions which leave no room for doubt that they are true spores. The sporangium is about ·042 in length; fig. 17 being enlarged about 110 diameters. Fig. 18 represents the portion containing the zygospores, enlarged about 290 diameters. The spore, fig. 18, *a*, is obviously identical with the form which I designated *Z. brevipes*; but the peripheral radii in fig. 18, *b*, are longer than in my fig. 51 (Memoir, Part X., Plate 19), and approach, in that respect, fig. 54 of the same plate, to which latter form I gave the name of *Z. longipes*, indicating that these are but extreme forms of one species. Other fragments now in my cabinet leave little, if any, doubt in my mind that these spores are identical with those of the fruit figured in my memoir, Part V., Plate 5, figs. 28, 29, and 30, under the name of *Volkmannia Dawsoni*.* Under these circumstances the provisional name of *Zygosporites* may be cancelled, as no longer needed, the spores to which it was applied being recognized as those of *Volkmannia Dawsoni*.

---

* This fruit was assigned to the genus *Volkmannia* at a time when that genus was much clearly less defined than it now is. BRONGNIART, going further even than had previously been done by UNGER,

Calamites.

Our knowledge of the structure of the cortical tissues of Calamites is yet very imperfect. A specimen from the Gannister bed at Moorside, near Ashton-under-Lyne, for which I am indebted to Mr. GEORGE WILD, supplies a new fact. In the memoir, Part IX., figs. 8–10 and 13, I have represented the primitive undifferentiated state of the cortical parenchyma of Calamites; and in figs. 14 and 15 of the same memoir, I have shown that a thick prosenchymatous layer was formed in the bark of some older stems. In Mr. WILD's specimen, fig. 19, the vasculo-medullary axis presents the usual features, except that the vascular wedges are more detached than ordinary owing to the partial disappearance of the cells of the primary medullary rays. The innermost bark, *a*, differs but little from the primitive state seen in the figs. 8–10 and 13 just referred to; but at *b* we have a hypodermal zone of specialised bundles of what seem to have been prosenchymatous cells. Each bundle has a triangular section, the apex being centripetal, and is from ·012 to ·008 from base to apex. The outermost bark, *c*, appears to have been a thin epidermal layer, some ·003 to ·002 in thickness. The peripheral border of this zone is sharply defined and entire, being wholly devoid of the crenulated contour so long supposed to have characterised the exteriors of sections of the Calamites. Every definite fact hitherto discovered demonstrates that those outer surfaces possessed neither longitudinal flutings nor nodal constrictions. Whether the fibrous bundles just described are the beginnings of the prosenchymatous zone shown in figs. 14 and 15 of my ninth memoir, or whether they are peculiar to some special form of Calamite, cannot now be determined. The specimen described has a diameter of ·25.

Lepidodendroid plants.

In several of my memoirs I have called attention to the gradual growth that took place in the diameter of the Lepidodendoid medulla owing to the multiplication of the medullary cells, and also to a contemporaneous increase that took place in the size of the surrounding non-exogenous vascular cylinder or "étui medullaire" of BRONGNIART, as well as in the number of its component vessels. Hitherto, however, I have failed to discover any example of *natura naturans* in either of these respects. But I found in a collection of sections submitted to me by Mr. NORMAN, of City Road,

---

united *Volkmannia* with *Asterophyllites*, believing the former to be the fruiting branches of the latter. But the limits and distinctive characteristics of the genus *Asterophyllites* are themselves undefined, and, as yet, *sub judice*. Since I cannot identify my *Volkmannia Dawsoni* with any of the genera recognized by SCHIMPER or by Professor WEISS, of Berlin, and I have not, as yet, obtained so accurate a knowledge of the orientation of the sporangiophores as would alone justify me in making it the type of a new genus, the strobilus may be left provisionally where I placed it in my previous memoir.

London, a section of a *Lepidodendron* of the type of *L. Harcourtii*, in which nearly every one of the cells is in a state of simultaneous meristemic division. Fig. 20 represents a small portion of this section. The entire stem has a diameter of about 1·75; the vascular cylinder is about ·37 and the medulla about ·3 in diameter. Fig. 20, *a*, are the large vessels of the vascular cylinder. At *b* we have the thick, older, cell-walls of the medullary cells, whilst at *c* we have the newly formed septa by which each older cell is becoming divided into two or more new ones. The older cells exhibit the form of regular parenchyma; the new ones are extremely irregular in size and form, and would obviously require to undergo a considerable expansion, leading to a steady enlargement of the entire medulla, before they attained to the regular forms of the parent cells. Every fact observed thus far indicates that the vascular cylinder, *a*, develops centripetally, and that the multiplication of the medullary cells here demonstrated to have existed was preparatory to the conversion of the outermost of them into new vessels. The known facts of enlargement in the sizes of and in the number of vessels composing the vascular cylinder thus receives a probable explanation.*

Halonia.

In my memoir, Part II., p. 222, *et seq.*, I described the organization of some *Haloniæ* in which the central axis consisted, as in most of the young Lepidodendroid branches, of a central medulla surrounded by a vascular, non-exogenous cylinder. Thanks to Professor YOUNG and Mr. J. YOUNG, of the Glasgow University, I am now able to describe another interesting form of *Halonia* from the Arran deposits of Laggan Bay. In my descriptions of the Lepidodendroid plants from that locality (Memoir, Part X., p. 494) I pointed out that in *all the small* Lepidodendroid twigs, occurring so abundantly in those beds, the central axis was a solid, non-cylindrical, bundle of vessels (*loc. cit.*, Plate 14, figs. 1 and 2). Fig. 21 represents a section of the Arran *Halonia* which has a mean diameter of about ·87—a small portion of its peripheral cortical tissue having disappeared. The central axis, *a*, consists of a solid rod of barred vessels—resembling, in this respect, the young twigs with which it was found associated in the Arran beds. The surrounding cortical layers consist, as usual, of an innermost bark at *b*, composed of rather compressed but regular parenchyma, the cells of which are small, averaging about ·0012 in diameter. The space, *c*, seems to have been occupied by very similar cells, only a few of which remain. At *d* we have a middle bark, composed of larger and coarser parenchymatous cells, and at *e* is the usual prosenchymatous layer, the small cells of which are arranged in radiating series. In the specimen from which my sections were prepared the protuberances so charac-

---

* Though this addition to the number of the vessels appears to be made at the centripetal border of the vascular cylinder, *a*, it must not be supposed that this addition reduces the diameter of the medulla. Unlike what occurs amongst Phanerogams, the medullæ of many *Lepidodendra* obviously continue to enlarge long after the development of the exogenous zone.—July 8, 1883.

teristic of the *Haloniæ* are sufficiently conspicuous, and in the sections we can readily distinguish between the vascular bundles going off to these protuberances, and those supplying the leaves. Three of the former are seen at *f, f, f.* They have a mean diameter of about ·004. In the case of the *Halonia* previously described, the corresponding bundle was formed by the detachment of a small but complete segment of the vascular cylinder leaving a break in the continuity of the latter. In the present case the bundle is formed in the way represented in the three transverse sections, figs. 22, 23, and 24. In all these sections, *a* represents a portion of the solid vascular axis of the branch. In fig. 22 two indentations at *b, b* are separating the clusters of vessels, *f*, from the main bundle. In fig. 23 the bundle, *f*, is almost entirely separated, whilst in fig. 24 it is completely detached from the axial bundle, and is moving outwards through the middle bark as in fig. 21, *f, f.* These bundles are distinguished from the foliar bundles by their size; fig. 25, *a*, represents a portion of the cylinder giving off a foliar bundle, *b*.

This section, drawn to the same scale as the other three, exhibits the relative sizes of these two classes of bundles. We further see that many of the larger ones proceeding to the tubercles are surrounded by small foliar bundles of their own—destined, doubtless, to supply the leaves clothing these prominences characterising the *Halonia*.

This hitherto undescribed form of *Halonia* raises anew the question whether or not Plate 10, figs. 1 and 2, of my Part X. is a younger state of the plant represented in figs. 3 and 4 of the same plate. The two are identical in every feature other than the structure of these axial bundles, which is solid in the one and a hollow cylinder enclosing medullary cells in the other. The present position of the question is as follows:—

As stated in my previous memoir, the central axis of each of the very young Lepidodendroid twigs, so abundant in the Laggan Bay deposit, consists of a solid vascular bundle having a diameter of ·012. The similar solid axis of the new *Halonia*, belonging to a branch of larger size, has a diameter of ·14. I have recently obtained from the same locality an ordinary Lepidodendroid branch of about the same dimensions as the *Halonia*, of which the axial bundle is also a solid one, with a diameter of ·14. This is the largest example I have met with having a *solid* bundle. On the other hand, the smallest of the many Lepidodendroid branches and stems from Arran which my cabinet contains, possessing a *hollow* cylindrical vascular axis, is that figured in my memoir, Part X., figs. 3 and 4. In that specimen the vascular zone surrounding the central medulla has a diameter of ·2, from which figure all these cylinders increase steadily in diameter, in the number of their component vessels, and in the dimensions of the cellular medulla which they enclose, until we reach the largest axial bundles of the arborescent stems.* The fact that all the specimens hitherto found *below* a certain diameter have the *solid* vascular bundle whilst all *above* that

* This increase seems to be partly explained by what I have said on p. 466 about fig. 20.

diameter have the *hollow* ones, inclines me to adhere to my former opinion that these differences are merely due to age: a conclusion strengthened by the fact that *solid* axial bundles are equally absent from *every* specimen of considerable size that we have as yet obtained from any British locality. At the same time it is possible that this opinion may some day require modification.

The late Mr. BINNEY held the view that the *Haloniæ* were the roots, and not the branches, of some Lepidodendroid plants. M. RENAULT, in his recent 'Cours de Botanique Fossile,' advocates the view that some *Haloniæ* are what he terms "Stigmarhizomes" or semisubterranean creeping stems. Structural evidence compels me to reject both these conclusions.* Mr. CARRUTHERS arrived at the same conclusion as I had done from his study of some specimens which he described in 1873.† Recently visiting the museum of the Leeds Philosophical Society, I found on their shelves the magnificent and most conclusive specimen of a branching *Lepidodendron*, the terminal subdivisions of which are true *Haloniæ*, represented in fig. 26. I am indebted to Professor MIALL for an excellent cast of this specimen, from which cast Mr. BROTHERS, of Manchester, prepared the beautiful photograph copied in the above figure. It is yet more perfect than Mr. CARRUTHERS' specimen, since its lower extremity, *a*, exhibits much more markedly than his corresponding ones do the elongated foliar cicatrices characteristic of the *Lepidodendra*. At the lower portion of the branch, A, these leaf-scars have exactly the same form as those of *L. selaginoides* and *L. elegans* of LINDLEY and HUTTON. After its first bifurcation, the two branches, B, B, still retain much of their Lepidodendroid features, though the leaf-scars gradually become less elongated vertically. Towards the upper part of each of the branches, B, B, we discover the first traces of the tubercles characteristic of *Halonia*. These become yet more conspicuous and numerous in the terminal branches, C, C, where we also find that the foliar cicatrices are equilateral rhomboids, instead of the vertically elongated scars seen at A; their vertical and transverse diameters being now about equal. The difference between the two forms is shown to be due in this instance, not only to differences between the several cortical layers, but to the fact that these branches, like their parent stems, have grown more in length than in breadth. This is proven by the circumstance that we can trace the gradations from the one form to the other in the same continuous cortical surface. These Halonioid branches are obviously identical with the *Halonia tortuosa* of LINDLEY and HUTTON.

---

[*] See memoir, Part II., p. 222, Phil. Trans., 1872. In the work referred to above, M. RENAULT endeavours to draw a distinction between *Haloniæ*, which he believes to be the subterranean rhizomes, and those which he recognizes as branches of *Lepidodendron*. He includes in the former class, which he thinks differs from his second one in the rarity with which dichotomous branching occurs in the *Haloniæ* belonging to it, the well-known *Halonia regularis*. This distinction is a purely imaginary one. *Halonia regularis* dichotomises freely.—July 7th, 1883.

[†] "On *Halonia* of LINDLEY and HUTTON and *Cyclostadia* of GOLDENBERG," Geol. Mag., vol. x., No. 4, April, 1873.

In my second memoir (Phil. Trans., 1872, p. 222), read in June, 1871, I said, "I have little doubt but that *Halonia* was a fruit-bearing branch of a *Lepidodendron;*" and in a note added in April, 1872,* I affirmed *absolutely*, "First, that *Halonia* belongs to the upper branches of a Lepidodendroid tree, consequently it cannot be a root;" "Secondly, we learn that *Halonia* is a specialised branch of a Lepidodendroid tree that is not itself a *Halonia*." These conclusions were further supported by Mr. CARRUTHERS in his memoir on *Halonia* and *Cyclostadia*, already referred to as published in April, 1873, and in which the author, speaking of the specimen which he then described, says, "With *Bergeria* must go *Halonia* as a separate genus, seeing that it is only a condition of *Lepidophloios;* and it may be of other Lepidodendroid plants." The specimen now described is unquestionably not a *Lomatophloios* but a true *Lepidodendron*. The figure on Plate 8 is slightly reduced in size.

Sporocarpon.

In my tenth memoir (Phil. Trans., 1880) I figured in Plate 18, fig. 39, and described (p. 510), under the name of *Sporocarpon ornatum*, a curious form of what appeared to be some Cryptogamic fruit. I have recently received two additional specimens of this organism, one from Mr. EARNSHAW, of Oldham, and the other from Mr. WILD, of Ashton-under-Lyne, which, whilst they confirm my previously expressed conviction as to the character of this object, reveal some additional features connected with it. Mr. WILD's specimen, originally a perfect circle, but slightly damaged during the preparation of the section, is represented by fig. 27. As before described, this fruit is a spherical body with an undulating peripheral outline. In both the new specimens the undulations are more regular than in that previously figured, and in the centre, *a*, of each crenulated prominence there is a canal produced by reabsorbtion of some of the parenchymatous cells. On re-examining my original specimen I find some slight traces of a similar condition. On the other hand, in both my two new examples the peripheral clusters of large cells (*loc. cit.*, fig. 39, *d*) are wanting. These circumstances suggest that the latter are examples of a more advanced stage of growth than the former. It is not improbable that this structure has been primarily developed in the interior of some parenchymatous tissue, of which the large cells, *d*, of my original figure are remnants, but which fell off after the capsule became separated from its temporary surroundings.

Dadoxylon.

In my memoir, Part VIII., I figured (*loc. cit.*, Plate 8, figs. 44 and 46; Plate 9, figs. 47 and 48) and described (p. 230) some young branches of our British form of *Dadoxylon* in which vascular bundles are given off in pairs from the medullary border of the vascular cylinder, and observed respecting them, "This orientation of these small bundles from the innermost layers of the wood is suggestive of their primary relations to leaves rather than to branches;" and further pointed out that they differed only from similar leaf-bundles in living Conifers only in being in pairs instead of being single. From this I inferred that "Either two bundles went to one leaf with a double midrib, or the leaves were arranged in pairs."

---

* *Loc. cit.*, p. 225.

Since these remarks were penned I have examined various living Conifers in hope of finding in some of them a similar organization: I have succeeded in the case of *Salisburia Adiantifolia*, but in it alone. Fig. 28 represents a transverse section of a twig of that plant of the first year's growth, made immediately below the terminal leaf-bud. At *a* we have the medulla and the xylem zone at *b*; *c* is the cambium layer with newly forming xylem and phloëm zones.* At *d* is an inner and at *e* an outer cortical zone. Many of the cells of the medulla and of the inner bark contain large sphæro-raphides, these two tissues thus furnished being portions of the primitive fundamental tissue; the outermost bark, *e*, being an incipient cork periderm. At *f*, *f* we find the xylem ring interrupted by extensions of the medulla—which connect the latter with the cortical fundamental layer. Two vascular bundles, *g*, are given off from the vascular zone, one on each side of this extension of the medulla, and proceed outwards, diverging but slightly as they ascend towards the periphery, which they reach in pairs, as at *g′*, *g′*. In fig. 29 we have a transverse section of the petiolar base of one of the outermost leaf-scales of the leaf-bud, in which we again find a pair of these bundles, *g*, entering the leaf-scale. The prosenchymatous tracheides of each of these bundles are arranged in six or seven parallel and somewhat fan-shaped, radiating rows. In the matured leaf these two bundles obviously subdivide to form the well-known venation of the *Salisburia*.

Seeing that this twin development of the foliar bundles appears to be limited, amongst living Conifers, to the *Salisburia*, in which plant it seems to hold a definite relationship to the peculiar multinerved structure and Adiantiform contour of the leaf, may we not recognize the probability that our British carboniferous *Dadoxylons* bore some remote genetic relations to the living Gingko? No such duplex leaf-bundle appears to have been detected in any of the fine examples of *Cordaites* and their allies discovered by M. GRAND-'EURY in the St. Étienne deposits. This Salisburian form seems to be confined to our British *Dadoxylons*. That this similarity of contour in the arrangement of the leaf-bundles is not merely accidental is rendered the more probable by the fact that transverse sections of young twigs of the ancient and modern plants display corresponding identities. Thus a section of the bark of a young *Dadoxylon*† corresponds closely with the similar section of a *Salisburia*, fig. 28, in both of which the bark is separated into an outer coarsely cellular periderm and an inner one composed of much more delicate elements. This observation applies to the

---

* The section was made in April.

† See Memoir VIII., fig. 34.

Salisburia, whether in its young state, when the inner bark consists, as represented in fig. 28, of undifferentiated primitive parenchyma, or, in a later stage of growth, when the bark is distinctly differentiated into an inner translucent phloëm and an external phellem layer. These correspondences between the carboniferous *Dadoxylon* and the living *Salisburia* suggests another query. The resemblances between the fossil *Trigonocarpums* of the Coal-measures and the fruits of the Gingko have long been noticed. Do not the facts just mentioned increase the probability that these *Trigonocarpums* are the fruits of *Dadoxylon?* I not only think they do, but these facts suggest the further possibility, not to say probability, that our *Dadoxylons* may be the remote Carboniferous ancestors of the oolitic *Baierias*—already recognized as the ancestral forms whence sprang the *Salisburias* of Cretaceous and yet more modern times.

I have again to recognize my obligations to Messrs. CASH, SPENCER, and BINNS, of Halifax; to Mr. HICK, of Harrogate; to Mr. WILD, of Ashton-under-Lyne; and to Messrs. BUTTERWORTH and EARNSHAW, of Oldham, for their valuable aid in searching for specimens calculated to aid my investigations.

INDEX TO THE PLATES.

PLATE 27.

Astromyelon Williamsonis.

Fig. 1. Transverse section of a non-exogenous branch (?). Enlarged 70 diameters. *a.* Vasculo-cellular axis. *b* and *c.* Inner cortical zones. *d.* Radiating cellular laminæ. *e.* Outer cortical parenchyma. Mr. SPENCER.

PLATE 28.

Fig. 2. Transverse section of a stem. Enlarged 55 diameters. *a.* Large cellular medulla. *b.* Young exogenous zone, feebly developed. *c.* Innermost bark. *d.* Radiating laminæ. *d''.* Lacunæ separating the laminæ *d.* *e.* Peripheral parenchyma. Messrs. CASH and HICK.

PLATE 27.

Fig. 3. Transverse section of a stem. *a.* Medulla. *a'.* Cluster of thick-walled vessels at the inner angle of each large vascular wedge. *b.* Vascular wedges. *c.* Innermost bark. *d.* Radiating laminæ. *e.* Outer parenchyma. Mr. SPENCER.

PLATE 31.

Fig. 4. Vertical section of a stem passing obliquely through the outer cortical parenchyma at its upper end, and through the centre of the medulla at its lower one. Enlarged 40 diameters. *a.* Medullary cells. *b.* Vascular zone. *c.* Innermost cortex. *d, d′.* Radiating laminæ. *d″.* Lacunæ. *e.* Outer cortical parenchyma. Messrs. CASH and HICK.

PLATE 30.

Fig. 5. Transverse section. Enlarged 55 diameters. *a.* Central axis, chiefly or wholly composed of vessels. *b.* Exogenous zone. *c.* Inner cortex. *d.* Radiating laminæ. *d″.* Lacunæ. *e.* Outermost cortex. *f.* Vascular bundle going off to some lateral appendage. Mr. SPENCER.

PLATE 28.

Fig. 6. Transverse section of a stem, enlarged 55 diameters, but having a much thicker outer cortex. References as in fig. 5. Mr. SPENCER.

PLATE 29.

Fig. 7. Section through a branching structure. Enlarged 55 diameters. At A is an obliquely transverse section through a branch. *a.* Central axis composed of a cluster of cells and vessels. *c.* Delicate elongated cells of the inner bark. *d.* Radiating laminæ. *d″.* Lacunæ. *e.* Outer cortical parenchyma. At B is an almost longitudinal section through a dichotomising branch. References as at A. At C is a small vascular bundle, *a‴*, passing outwards. Mr. SPENCER.

PLATE 28.

Fig. 8. Form of vascular tissue. Enlarged 267 diameters.
Fig. 9. Form of vascular tissue. Enlarged 267 diameters.

PLATE 29.

Fig. 10. Form of vascular tissue. Enlarged 267 diameters.
Fig. 11. Form of vascular tissue. Enlarged 524 diameters.
Fig. 12. Form of vascular tissue. Enlarged 267 diameters.
Fig. 13. Form of vascular tissue. Enlarged 267 diameters.

PLATE 31.

Fig. 14. Form of vascular tissue. Enlarged 267 diameters.

PLATE 30.

Fig. 15. Transverse section of a small organism from Halifax. Enlarged 214 diameters. Mr. SPENCER.

Psaronius Renaultii.

Fig. 16. Transverse section of a portion of an arborescent stem. Enlarged 2½ diameters. *a*, *a'*. Fibro-vascular bundles. *b*. Phloëm layer investing each bundle. *c*. Small gum-canals. Mr. WILD.

PLATE 31.

Zygosporites.

Fig. 17. Sporangium from Halifax containing *Zygosporites*. Enlarged 110 diameters.

PLATE 32.

Fig. 18. Portion of fig. 17. Enlarged 290 diameters.

PLATE 33.

Calamites.

Fig. 19. Transverse section of a young Calamite from the Gannister bed at Moorside, Ashton-under-Lyne. Enlarged 20 diameters. *a*. Innermost cortex. *b*. Hypodermal zone of prosenchymatous vertical bundles. *c*. Epidermal (?) layer. *d*. Vascular wedges of the exogenous zone. *e*. Fistular medullary cavity. Mr. WILD.

Lepidodendron and Halonia.

Fig. 20. Portion of a transverse section of the medulla and vascular medullary sheath of a *Lepidodendron*. Enlarged 190 diameters. *a*. Vessels of the medullary sheath. *b*. Older medullary cells. *c*. Septa of newly-forming cells. Mr. NORMAN.

PLATE 32.

Fig. 21. Transverse section of a branch of *Halonia* from Arran. Enlarged 5 diameters. *a.* Central vascular axis. *b.* Innermost portion of the inner cortex. *c.* Outer part of the same, chiefly destroyed. *d.* Middle cortical parenchyma. *e.* Prosenchymatous cortical layer. *f, f.* Large vascular bundles supplying the Halonial protuberances. Professor YOUNG and Mr. J. YOUNG, Glasgow.

Fig. 22. Segment of the periphery of the vascular axis of another section of the specimen fig. 21. *a.* Vessels of the central axis. *b.* Constrictions of the axis separating the vessels, *f*, from it. Enlarged 54 diameters.

PLATE 33.

Fig. 23. Similar section to fig. 22, only with the clusters of vessels, *f*, completely detached from *a* to form a bundle supplying one of the Halonial tubercles. Enlarged 54 diameters.

PLATE 32.

Fig. 24. Similar section to the last, but with the tubercular bundle completely free in the inner bark. Enlarged 54 diameters.

Fig. 25. Similar section to the three last, showing the size of the *foliar* bundle, *b*, relatively to the tubercular ones.

PLATE 34.

Fig. 26. Dichotomous branch of a *Lepidodendron* terminating in smaller Halonial branches. Slightly reduced in size. *a.* Lower extremity of the branch, with oblong leaf-scars like those of *L. elegans* and *selaginoides*. *b.* Leaf-scars becoming more rhomboidal. *c.* Halonial tuberculated portions with the rhomboid leaf-scars of *Bergeria*. Professor MIALL.

PLATE 31.

Sporocarpon anomalum.

Fig. 27. Transverse section. Enlarged 55 diameters. *a.* Canal in the centre of each crenulation.

PLATE 33.

Salisburia adiantifolia.

Fig. 28. Transverse section of a young twig of the first year, made immediately below a terminal bud. Enlarged 17 diameters. *a.* Medulla, with numerous sphæroraphides. *b.* Xylem. *c.* Cambium and new fibro-vascular elements. *d.* Inner cortical zone of primitive cortex with sphæroraphides. *e.* Incipient cork periderm. *f.* Breaks in the xylem-ring where pairs of foliar bundles, *g*, are given off. *g'*. Pairs of similar bundles reaching the periphery of the bark.

Fig. 29. Transverse section of the petiolar base of a leaf-scale from the terminal bud. Enlarged 24 diameters. *g*. Pair of fibro-vascular bundles.

XII. *Experimental Researches on the Electric Discharge with the Chloride of Silver Battery.*—Part IV.

By Warren De La Rue, *M.A., D.C.L., Ph.D., F.R.S., and* Hugo W. Müller, *Ph.D., F.R.S.*

Received June 11,—Read June 14, 1883.

[Plates 35, 36.]

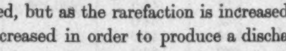
TUBE-POTENTIAL.

Pressure of least resistance dependent on the shape and dimensions of vessel.

We have already stated that the potential necessary to produce a discharge in partially exhausted tubes diminishes with the pressure until a certain pressure of minimum resistance has been reached, but as the rarefaction is increased beyond this point, then the potential has to be increased in order to produce a discharge.* The experiments on which this result was founded were made with a tube 33 inches (83·8 centims.) long and 2 inches (5·1 centims.) in diameter, and it was found that in a hydrogen partial vacuum the pressure of minimum resistance was 0·642 m.m., 845 M. Professor Stokes suggested the desirability of making experiments with a wide tube, or, still better, with a globe, as it would allow the discharge to spread laterally and diminish the resistance thereby, and, very probably, alter the pressure of minimum resistance. He considers this to be a question of importance with reference to the height of the aurora, for in the atmosphere there is ample space for lateral expansion, and it is conceivable that the least resistance may correspond to a pressure a good deal different from that which gives the least resistance in a tube.

Experiments were made in an air residue contained in a vessel in some measure resembling a prolate spheroid, 7 inches (17·8 centims.) long and 5 inches (12·7 centims.) in diameter, the distance between the terminals, one a cup, positive, the other heart-shaped, negative, was 3⅝ inches (9·2 centims.) (see fig. 1). The battery employed

Fig. 1



---

* Part III., Phil. Trans. for 1880, vol. 171, Part I., p. 65 (separate copy, p. 159).

consisted of 11,000 cells, giving a deflection when short-circuited of 49° with a total internal resistance of 360,800 ohms.

On June 17, 1881, the following results were obtained :—

Pressure.			Deflection.	Total resistance.	Tube-resistance.	Tube-potential V.
m.m.	M.	Cube root of M.	°	ohms.	ohms.	cells.
35·0	46,053	35·84	33·0	639,700	278,900	4796
33·5	44,079	35·32	40·0	495,000	134,200	2982
31·0	40,789	34·42	43·0	445,300	84,500	2089
27·5	36,184	33·08	40·0	495,000	134,200	2982
26·0	34,211	32·46	43·0	445,000	84,500	2089
24·0	31,579	31·61	43·0	..	..	..
21·5	28,290	30·47	43·0	..	..	..
19·5	25,658	29·50	43·0	..	..	..
16·0	21,053	27·61	44·0	430,700	69,900	1784
13·5	17,763	26·09	45·0	415,000	54,200	1435
10·5	13,816	24·00	46·0	400,300	39,500	1085
8·5	11,184	22·36	46·5	393,500	32,700	913
6·5	8553	20·45	46·5	..	..	..
4·5	5921	18·09	48·0	374,000	13,200	388
3·5	4605	16·64	48·5	367,400	6600	194
2·5	3290	14·87	47·0	386,700	25,900	737
2·0	2632	13·81	47·0	..	..	..
1·5	1974	12·54	47·0	..	..	..
1·0	1316	10·96	46·0	400,300	39,500	1085
0·47	618	8·52	44·0	430,700	69,900	1784
0·31	408	7·42	44·0	..	..	..
0·16	211	5·95	44·0	..	..	..
0·06	79	4·29	44·0	..	..	..
0·03	39	3·39	44·0	..	..	..
0·02	26	2·96	38·0	531,600	170,800	3534

On June 22, the following :—

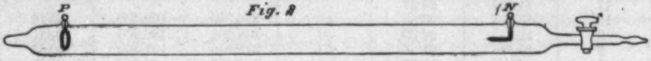
Battery 11,000 cells, short circuited, gave a deflection of 65°, and a total internal resistance of 193,600 ohms.

Pressure.			Deflection.	Total resistance.	Tube-resistance.	Tube-potential V.
m.m.	M	Cube root of M.	°	ohms.	ohms.	cells.
21·0	27,634	30·23	60	239,500	45,900	2108
18·0	23,684	28·72	..	..	..	..
15·0	19,737	27·03	61	230,200	36,600	1749
9·0	11,842	22·79	..	..	..	..
7·0	9211	20·96	..	..	..	..
5·0	6579	18·74	62	320,900	27,300	1360
3·0	3947	15·80	63	211,600	18,000	936
2·0	2632	13·80	..	..	..	..
1·1	1447	11·31	62	220,900	27,300	1360
0·67	882	9·59	..	..	..	..
0·17	224	6·07	59	249,500	55,900	2464
0·10	132	5·09	..	..	..	..
0·04	53	3·75	57	263,600	70,000	2920
0·16	21	2·76	51	336,200	142,600	4666

In both of these series of experiments it will be seen that the pressure of minimum resistance for an air partial vacuum in the vessel of spheroidal shape and of the dimensions mentioned is about 3 m.m., 3947 **M**, corresponding to the pressure of air at an altitude of 27·42 miles, at which height the aurora would from these data have a maximum brilliancy and would be visible at a distance of 499 miles. This result is very different from that before cited, which was obtained with a hydrogen tube from which the pressure of maximum brilliancy was deduced to be for air 0·379 m.m., 499 **M**.,* at a height of 37·67 miles and visible at a distance of 585 miles.

As no direct experiments had been made for an air residual vacuum in smaller tubes, the following investigations were made with a tube, No. 342, 1·625 inch (4·1 centims.) in diameter and 22·5 inches (57 centims.) between the terminals, one a ring positive, the other a point negative (see fig. 2, on the same scale as fig. 1).

Fig. 2



BATTERY 11,000 cells, deflection when short-circuited 70°, showing a total internal resistance of 151,000 ohms. At a pressure of 19 m.m. there was a glow on each terminal, but the current was not sufficient to deflect the galvanometer used until it had been lowered to 14 m.m.

Pressure.			Deflection.	Total resistance.	Tube-resistance.	Tube-potential V.
m.m.	M	Cube root of M.	°	ohms.	ohms.	cells.
14·0	18,421	26·41	46	400,300	249,200	6848
12·0	15,789	25·09	55	291,200	140,100	5291
11·0	14,474	24·37	55	..	..	..
10·0	13,158	23·59	55	..	..	..
9·0	11,842	22·79	56	280,400	129,300	5072
8·0	10,526	21·58	57	263,600	112,500	4693
7·0	9211	20·96	60	239,500	88,400	4061
5·0	6579	18·74	61	230,200	79,100	3780
3·0	3947	15·80	62	220,900	69,800	3477
2·0	2632	13·81	62	..	..	..
0·69	908	9·68	63	211,600	60,500	3146
0·23	303	6·72	62	220,900	69,800	3477
0·15	197	5·82	60	239,500	88,400	4061
0·05	66	4·04	57	263,600	112,500	4693
0·03	39	3·39	54	302,100	151,000	5499

The pressure of least resistance is therefore 0·69 m.m., 908 **M**., in the tube in question, and it does not differ materially from 0·642 m.m., the pressure of least resistance in hydrogen.

A pressure of 0·69 m.m. corresponds to an atmospheric height of 34·71 miles, and an aurora at this height would be visible at a distance of 561·4 miles.

---

* Proc. Roy. Soc., No. 203, 1880.

Another experiment made with a tube (fig. 3, on the same scale as fig. 1) 0·75 inch (1·9 centim.) in diameter, and 23 inches (58·4 centims.) long between two terminals, both paraboloidal in form, gave the following results :—

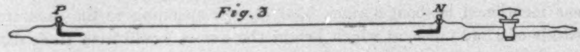


Fig. 3

Pressure.			Deflection.	Total resistance.	Tube-resistance.	Tube-potential V.
m.m.	M.	Cube root of M.	°	ohms.	ohms.	cells.
14	18,421	26·41	45	415,000	203,400	5392
13	17,105	25·75	46	400,300	188,700	5186
12	15,789	25·09	47	386,700	175,100	4979
11	14,479	24·37	..	..	..	..
10	13,158	23·59	48	374,000	162,400	4776
9	11,842	22·79	50	348,500	136,900	4321
8	10,526	21·58	53	313,000	101,400	3563
6	7895	19·91	56	280,400	68,800	2699
5	6579	18·74	..	..	..	..
3	3947	15·80	59	249,600	38,000	1674
2	2632	13·81	60	239,500	27,900	1281
1	1316	10·95	61	230,200	18,600	888
0·5	658	8·69	58	253,300	41,700	1811
0·08	105	4·72	47	386,700	175,100	4979
0·04	53	3·76	34	897,300	685,700	8407

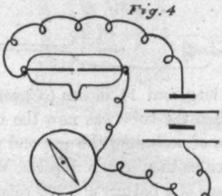
The pressure of minimum resistance in this particular case is 1 m.m., 1316 M, which is the same as that of the atmosphere at a height of 32·87 miles, where an auroral display would be visible at a distance of 546·6 miles. It is evident therefore that not only the dimensions of the tube, but possibly also the shape of the terminals, have a marked influence on the pressure of least resistance, and it is very probable that in the atmosphere where the lateral expansion is practically unlimited, the conditions of minimum resistance are different from those which exist even in large tubes.

The foregoing experiments, which show that the pressure of minimum resistance is not absolute for any particular gas, but that it varies with the size and form of the vessel containing it, seem to point to the conclusion that the carrier of electricity must be ponderable matter, and not the ether as has been suggested. Professor STOKES considers it most probable "that the presence of ponderable matter is necessary for the transfer of electricity from one place to another. At moderate exhaustions there are plenty of molecules, but they are so close that they hamper one another's motions. As the exhaustion is carried further there are still plenty of molecules, but they hamper one another less, and therefore the facility for the transfer of electricity is increased. But when the exhaustion becomes extreme, there is a loss in the facility of transfer from not having enough molecules; and as the exhaustion is still further continued, it is easily conceived that more may be lost, in point of facility of transfer, than is gained by increasing freedom in their motions. In a wide space the impediment to free motion is less than in a confined tube, and it is natural, therefore, that the effect of increasing fewness of the molecules should begin to tell at an earlier stage of exhaustion : that is, that the pressure of minimum resistance should be greater than in a tube." Later on we shall quote other experiments on the difference of potential in different parts of a tube in support of this view.

Discharge in miniature tubes.

Experiments on the discharge in miniature tubes gave most unexpected results; for example, in a tube of the dimensions represented of the natural size in fig. 4, which also represents the arrangement of the apparatus. The terminals in this tube so nearly touched, that in order to ascertain that they were not in actual contact, they were connected through a sensitive galvanometer with the opposite poles of a battery of 10 cells. The battery-power was then increased gradually to 2400 cells, when a discharge took place. After this discharge, then a single cell would pass; but if the tube was allowed to stand for a short time (5 minutes) then it required 4800 cells to reproduce a discharge. From the great heat of the discharge the terminals became red-hot and the tube very soon cracked and prevented the repetition of the experiments.

Fig. 4



But in another tube of the size shown in fig. 5 fresh experiments were made, the terminals in this tube were distant about $\frac{1}{1000}$th of an inch (0·00104) (0·0264 m.m.), the points being of the form shown magnified in fig. 6 after a discharge had taken place.

Fig. 5

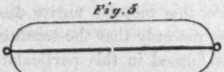
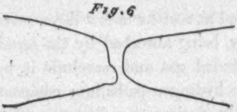


Fig. 6



After the discharge of 2240 cells had passed, then the number of elements had to be increased to 11,240 to produce a discharge, and at last even this number could not cause one except by alternating the current first in one and then in the contrary direction. Ultimately this failed to produce a discharge, but an induction coil did so;

the discharge, however, took place with more facility across the outside of the tube, at ordinary atmospheric pressure, or between the terminals of the coil which were distant $\frac{9}{16}$, 0·5625, inch (1·43 centim.).

The tube was sealed off and laid by for a few days, when it was found that 5100 cells would not pass, but that 8700 did so intermittently, and it required 10,160 to produce a continuous discharge. Subsequently 1200 cells passed, 20 would not do so even immediately after the discharge of the former number; 800 cells, 700, and then 600 passed; but after a while the last number was insufficient to produce a discharge. This tube shared the fate of the first tube and ultimately cracked. It is very possible that the strong discharge volatilized a portion of the terminals, which were of platinum, and that this condensed, or that they absorbed the residual gas so completely as to produce a vacuum too perfect to admit of a discharge taking place, and that, ultimately, sufficient of the occluded gas was again given off to render the discharge again possible.

Occlusion of gas by terminals.

The power of terminals to occlude gas and then under an electric discharge to give it off again is well exemplified by tube 48, the terminals of which are both of palladium. The tube is shown in fig. 7, one terminal is in the form of a helix, the other straight; it is 7 inches (17·8 centims.) long, and $1\frac{1}{2}$ inches (3·8 centims.) in diameter, and contains residual hydrogen. When the tube was new the terminals were bright, but by continued use in consequence of occluding the gas and giving it off again they have become mat or frosted, and porous to a certain depth. We usually cause the spiral to be negative; after the discharge of a battery of 1200 cells has passed for a few seconds the tube which was at first free from deposit, as in fig. 7, becomes coated more especially near the negative, with a mirror-like metallic deposit, as in fig. 8. After the tube has remained at rest for a few days, seven in one instance, this metallic mirror disappears entirely, being absorbed by the terminals; this shows not only that the terminals give off occluded gas and reocclude it, but that there is formed in this particular case a volatile hydrogen-palladium compound. Moreover, the vacuum appears to alter considerably during the discharge, for a stratification which is produced in the first instance ceases in a short time, but the tube regains its original condition by standing for a few days, and stratification is again produced.

Fig. 7.

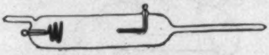
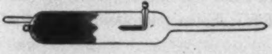


Fig. 8.

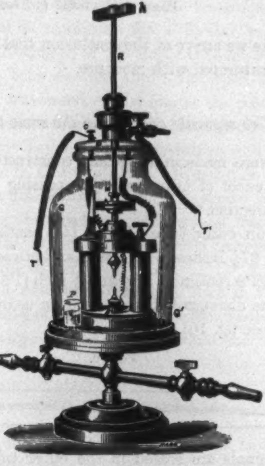


The phenomena described have been produced very many times and shown repeatedly to friends who have visited our laboratory since March 13th, 1875.

Length of spark in dry and in moist air.

Many experiments were made to ascertain the effect of saturation with aqueous vapour on the length of the striking distance; for this purpose the bell-jar and micrometer-discharger, as shown in fig. 9, were used.

Fig. 9.



The terminals employed were two paraboloidal points. The striking distance with 10,860 cells was found to be in air dried with phosphoric anhydride at a pressure of 30·345 inches (77·1 centims.) 0·57 inch (1·45 centim.).

The bell-jar was now removed and after having stood for a little while over a dish of water, was then replaced on the plate of the air-pump; in the bell-jar was placed a beaker, *p*, containing water to keep up the saturation, under these circumstances the striking distance was then found to be

	Inch.	
	0·58	(1·5 centim.)
after the lapse of 30 min.	0·58	(1·5 „)
„ „ 4 hours	0·55	(1·4 „)
„ „ 5 „	0·54	(1·4 „)

In another series of experiments with 8700 cells, the striking distance in dry air was found to be

	Inch.
	0·44
	0·45
	0·46
Mean . .	0·45 (1·1 centim.)
In air saturated with moisture	0·45
" " "	0·445
Mean . .	0·447 (1·1 centim.)

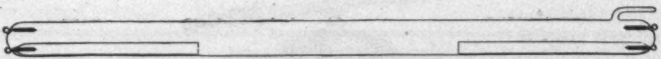
From these experiments we arrive at the conclusion that the striking distance is the same in dry air as in air saturated with moisture.

Two separate currents in the same tube.

Several experiments were made in a specially constructed tube with the object of ascertaining the mutual effect of two discharges passing within it first in the same and then in a contrary direction.

Tube 347 consists of an outer tube 1¾ inch (4·4 centims.) in diameter, 31 inches (78·7 centims.) long, and 27½ inches (69·8 centims.) between the terminals, two short pieces of tube, 9 inches (22·8 centims.) long and ½ inch (1·27 centims.) in diameter, are fixed one at each end; the distance between the open mouths of the small tubes being 13 inches (33 centims.) (see fig. 10).

Fig. 10.



Two paraboloidal terminals are sealed in the outer tube and two precisely similar ones are sealed in the small tubes and hold them in their places.

When the discharge from a battery of 3600 cells was made to pass through the small tube a close stratification, as in Plate 35, fig. 1, was produced, which stratification was continued in the interval between the open ends of the small tubes, but of an altered form, wider apart as shown in the figure, which is a facsimile of a photograph obtained on a dry plate in one second.

When the same discharge passed through the outer large tube a continuous stratification was obtained throughout, as shown in Plate 35, fig. 2.

When the discharges from two separate batteries, each of 3600 cells, were made to pass in reverse directions, the one in the outer tube having an external resistance of 250,000 ohms inserted, the discharge in the small tubes was the strongest, and an appearance was produced as shown in Plate 35, fig. 3.

It will be noticed that the effect of this stronger discharge is to completely reverse the convexity of the strata in the middle portion of the outer discharge in the large tube, while the convexity on the two extremities of the outer discharge retains its natural direction. It would appear, therefore, that the *natural* discharge in the intervening space in the outer tube is, as it were, replaced by a non-luminous one. When the batteries were kept on for about twenty seconds, or so, these intervening strata gradually diminished, and at last disappeared entirely, as shown in Plate 35, fig. 4, where they are replaced by a non-luminous space; but it is very evident, from the shape of the strata where visible, that two discharges continued to take place in the direction proper to each from both sets of terminals; the last stratum of the small tube on the positive side curving upwards into the broad space.

On keeping the batteries in connexion for a further period another remarkable change took place, and the discharge in the larger tube appeared to gain the mastery, its strata in the interval between and above the open ends of the small tubes reappearing with a forward movement one by one at the positive side, the convexities being turned towards the negative, which is the natural direction. The strata in the small tubes did not continue beyond their extremities, and a dark space intervened. These phenomena are shown in Plate 35, fig. 5. Keeping on the discharge still longer the strata in the small tube disappeared entirely, as shown in Plate 35, fig. 6.

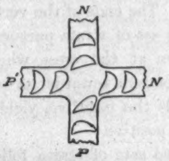
Ultimately, by continuing the discharge, both sets of the strata disappeared, as if one discharge neutralized the other, but these could be reproduced by breaking and remaking the contact with the batteries.

It is very probable when two discharges take place in the same tube in opposite directions that the column of gas becomes divided longitudinally into two layers, one of which conveys the discharge of one battery, while the other conveys that of the other battery.

Two separate currents crossing each other at right angles.

In order to ascertain the effect of two discharges from two distinct batteries crossing each other at right angles, we prepared a tube, No. 344, consisting of two tubes joined at right angles to each other, each tube being 33 inches (83·8 centims.) long and $1\frac{1}{8}$ inches (2·86 centims.) in diameter. The central portion is shown in fig. 11.

Fig. 11.



In the first place the discharge of a battery of 3600 cells was sent through one of the tubes containing air at a pressure 0·428 m.m., 563 M, causing a current of 0·01507 ampère, and producing the stratification which is represented in Plate 35, fig. 10;

which stratification is of the ordinary character, with the exception that, at the crossing of the two tubes, a wider stratum is produced. While the discharge was passing through only one of the tubes a faint illumination was also produced in the two branches of the other, but it was not stratified.

The two component tubes were subsequently connected with two separate batteries, each of 3600 cells, A and B; A with the poles P and N to the vertical component, and B with the poles P′ and N′ to the horizontal one. The effect is represented in Plate 36, fig. 15. It will be seen from the configuration of the strata at the cross, in this case when the currents were equal 0·00833 ampère, that the discharge of A goes from P towards N only as far as the cross, then turns off to the left to N′, the negative of the other battery, B, while on the other hand the discharge of B from P′ goes to the N of A battery.

The case is different if an external resistance is introduced in one of the discharges, as for instance in Plate 36, fig. 16, where, by the insertion of a resistance of 500,000 ohms in the B battery connected with the horizontal tube, the current was reduced to about one-tenth (0·00087 ampère) of that of battery A connected with the vertical tube, the discharge from A battery goes on direct from P to N and the discharge from B from P′ to N′. The different sizes of the two sets of strata render this evident. There is a bending down, however, of the strata of the weaker discharge at the cross in consequence of the action of the stronger one. One cannot but be impressed from this and other experiments before and hereinafter described by the apparent plasticity of the aggregate assemblage of molecules which constitute a stratum, for it evidently yields to external influences which modify its form. For instance, in Plate 36, fig. 17, copied from a photograph taken on a dry plate in half a second, the strata at the cross, produced by two equal batteries of 3600 cells, are so far modified in both tubes that the curvature of one stratum in each branch is made convex towards the positive instead of concave. The vacuum is of air at a pressure of 0·428 m.m., 563 M. The extremities of the vertical tube are both negative, and those of the horizontal tube positive, so that in each tube positive is opposed to positive and negative to negative.

In Plate 36, fig. 18, representing a photograph of the tube when containing hydrogen at a pressure of 0·46 m.m., with a separate discharge of 3600 cells in each tube, a very close stratification is produced. The ends of the vertical tube are both negative, those of the horizontal positive, each set of strata pursues its undisturbed course and produces a beautiful configuration at the cross where the last stratum in the two horizontal branches remains concave towards its own positive, but in the negative branch becomes convex towards the negative, yielding as it were to the influence of pressure of the strata from the positive.

In Plate 36, fig. 19, the two sets of strata follow their proper course leaving a dark interval at the cross between them. The tube contained air at a pressure of 0·423 m.m., 563 M, the batteries used being both 3600 cells, the positive of A battery was connected to the top of the vertical tube, and its negative to the left end of the horizontal tube. The positive terminal of B was connected to the right end of the horizontal tube, and its negative to the bottom of the vertical tube. The photograph from which this figure is copied was obtained in half a second.

Plate 36, fig. 20, represents the discharge through hydrogen at a pressure of 0·46 m.m., 605 M, batteries A and B, each of 3600 cells, the positive pole of A was connected with the left end of the horizontal tube, its negative to the top of the vertical, 2,600,000 ohms external resistance having been introduced in the discharge; the positive of B battery was connected to the right hand end of the horizontal tube, and its negative to the bottom. In neither set of discharges are distinct strata produced at the positive end, and only after passing the cross are such produced. It would almost seem that the resistance introduced in one pair of branches had offered an impediment to the discharge in the other.

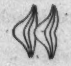
Effect on strata of the shape of the positive terminal.

Experiments were made in order to ascertain whether the *form* of a point used as a positive terminal had any effect on that of the strata. It was found, however, that whether the terminal was carefully shaped as a paraboloid, or was simply cylindrical, the strata took precisely the same form as is shown in Plate 35, where fig. 7 represents the discharge in hydrogen from a paraboloidal point, and fig. 8 that from a cylindrical point.

Complex strata.

The complex configuration of strata in many cases appears to us to present a great difficulty in accounting for their production, and in forming a clear conception of the forces which hold the molecules composing them so persistently together. Usually there is a dark space between the negative terminal and the last stratum on the positive side, but not unfrequently the last stratum or several strata thread themselves on to the negative when it consists of a wire, as, for instance, in tube 346, shown in Plate 35, fig. 9, containing hydrogen at a pressure of 0·5 m.m., 658 M, with a battery of 3600 cells, and an external resistance 200,000 ohms, producing a current of 0·00238 ampère. A beautiful bracket-like series of strata was produced, two or three of which threaded themselves on to the negative, as is distinctly shown in Plate 35, fig. 9. Looked at from the end it could be seen that these strata had circular holes in them larger than the negative wire, so that a small dark space was left. Each stratum consists of an outer bracket convex towards the negative and an inner chord (fig. 12).

Fig. 12.



Discharge in large tubes.

In Part III., pp. 197–201, we described some experiments with a large tube 37 inches (94 centims.) long, and $5\frac{13}{16}$ inches (14·8 centims.) in diameter. We have again taken up the study of the discharge in large tubes 3 feet 2 inches (96·5 centims.) long, and 6 inches (15·24 centims.) in diameter; the resulting phenomena are shown in Plate 35, figs. 11, 12, 13, and 14. In these, which are partly copied from photographs and partly from drawings made at the time in consequence of a to-and-fro movement of the strata preventing well-defined photographs from being obtained:—

Plate 35, fig. 11, exhibits a discharge of 8700 cells with a current of 0·049 ampère in carbonic anhydride at a pressure of about 0·5 m.m., 658 M. The strata near the terminals are not large enough to fill the whole bore of the tube, but they spread and become larger as they recede, and form a sort of conical expansion up to the wall of the tube. A rapid flow was observed from the negative with a still increased velocity, at intervals, producing a gap in the flowing strata of three times the interval between them. The three strata near the negative retained their position but rotated rapidly on their axes, and when looked at obliquely appeared dark in the centre and reminded one of a smoke vortex ring.

Plate 35, fig. 12, represents the appearance in a hydrogen vacuum of about 0·5 m.m., 658 M, with the same number of cells, 8700, producing a current of 0·047 ampère. After a short time the stratification receded towards the positive, leaving a long interval devoid of any towards the negative.

Plate 35, fig. 13, represents the appearance of a vacuum of nitrogen and bromine with the same number of cells, 8700, giving a current of 0·047 ampère. After the discharge had continued for a few seconds the strata, as in the case of hydrogen, receded towards the positive end of the tube as shown in Plate 35, fig. 14.

In all the foregoing cases a very beautiful and distinct stratification was produced, in the first instance, filling the tube just as in those of smaller bore, but near the terminals the strata became gradually smaller in a conical form, the gas itself for a certain distance acting as an enclosing tube.

The dark negative space.

In the dark space near the negative end of a vacuum tube the electric discharge is undoubtedly always passing, though not evident to the eye; but its passage is rendered apparent by the great heat at times developed within it, as we have already stated in Part II.[*] It occurred to us to endeavour to obtain a record of its passage by means of photography, and the result shows that it is actinically dark only by comparison. Tube No. 100, containing a residue of carbonic anhydride, gave, with 2400 cells and an inserted resistance of 200,000 ohms, a current of 0·00335 ampère, which produced a perfectly steady stratification during more than thirty-five minutes the tube was in connexion with the battery. In two and a-half seconds an impression of the strata was obtained on a dry plate, which is represented in Plate 36, fig. 21. The strata were then carefully covered so as to exclude all their light from the camera and to expose only the dark space; in fifteen minutes an impression was produced on the photographic plate, but it required an exposure of thirty-five minutes to produce an impression as dense as that obtained by an exposure of the strata for two and a-half seconds. The photographic intensity of the dark space is therefore 840 times less than that of the strata. The image of the dark space is shown in Plate 36, fig. 21, below that of the strata; it contains no trace of stratification, although, if any existed, it is fair to presume that it would have been depicted in consequence of the perfect steadiness of the discharge.

---

[*] Phil. Trans. for 1878, Vol. 169, Part I., p. 182, Exp. 47 (separate copy, p. 98).

Potentials at different nearly aliquot parts of a column of gas, at various pressures.

The following experiments, intended to ascertain the difference of potential in different parts of a vacuum tube,* bring out instructive information, not only in reference to the relative resistances of different lengths of a column of gas at various pressures, but also in regard of the impediment presented by the terminals themselves to the passage of a discharge from gas to terminal or terminal to gas.

They were made by means of an electrometer in connexion with an induction apparatus shown in fig. 13, and described in Part III. of our researches.†

In the present instance, however, certain modifications were adopted to prevent disturbing influences and to ensure concordant results. In the first place, a trap was formed to prevent the creeping down of electricity on the inside and outside, more especially the outside of the cylindrical glass shade enclosing the induction plates. This trap consists of two hoops of tin foil,‡ half an inch in width, pasted inside and outside respectively, about 4 inches below the flat top. Both these hoops communicate to earth by means of two vertical strips of tin foil pasted on the cylinder. Before this arrangement was adopted the cylinder became slowly charged, especially in damp weather, and unduly increased the deflection of the needle of the electrometer, by acting inductively on the induction plates.

It was found very advantageous to connect the needle with a small Leyden-jar§ (L, fig. 14), presenting a coated surface of 57 square inches (3·68 square decims.), and having a capacity of 0·0016 microfarad. The jar, by increasing the capacity of the apparatus, in a great measure obviates the disturbing influence of leakage during the

---

* Tube 149 with 12 aluminium rings, and tube 150 with 17 rings already described. Phil. Trans. for 1878 (vol. 169), p. 165; Part II. (separate copy, p. 81).

† Phil. Trans. for 1880, vol. 171, p. 112 (separate copy, p. 206).

‡ These are not shown in the engraving.

§ Part I. of our researches, Phil. Trans. for 1878, vol. 169, p. 99 (separate copy, p. 45).

Fig. 13.

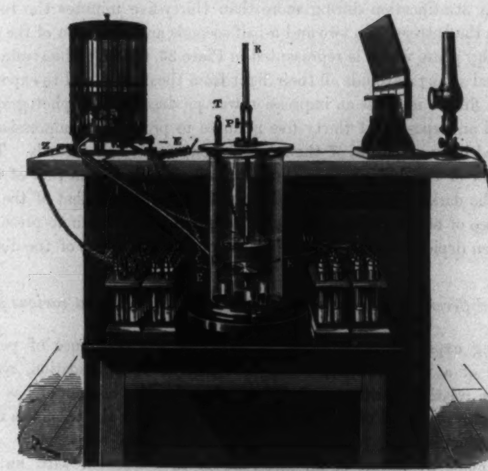
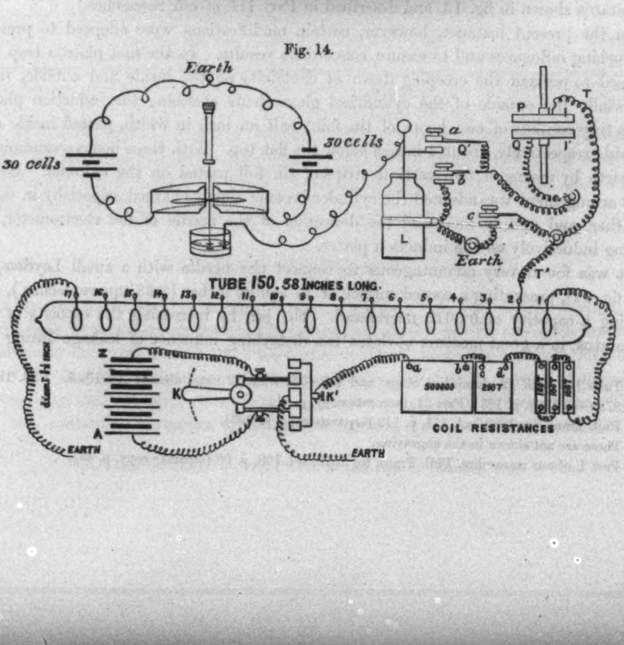

K
T
P
Z
E

Fig. 14.


Earth
30 cells
30 cells
a
Q'
b
P
T
Q
I'
c
L
Earth
T'
TUBE 150. 58 INCHES LONG.
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
diam.r 1¼ INCH
Z
K
K'
A
EARTH
EARTH
a
b
c
d
500000
200T
100T
100T
100T
COIL RESISTANCES

observations. For the suggestion of the Leyden-jar and the plan of observation about to be described we are indebted to Professor STOKES, by whose advice we have often profited. The arrangement of the apparatus is shown in fig. 14.

It will be seen on reference to fig. 14 that a battery of chloride of silver cells, the centre to earth, is used to charge up the opposite quadrants of the electrometer with electricity of opposite names. The number of cells is generally varied from 10 up to 60 in order to regulate the deflection, which can also be varied by varying the distance between the plates P and Q of the induction apparatus.

The needle is connected to the inside of the Leyden-jar L, the outside being permanently connected to earth. By pressing down the key *a* (which is supposed to represent a mercury connexion, as do also the keys *b* and *c*) the inside of the jar is connected with the induced plate Q; before, however, connecting the source of electricity with P, the key *b* is pressed down so as to connect the inside of the jar, the needle, and the induced plate Q to earth; this may be designated the Q system.

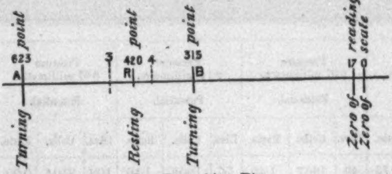
The source of electricity is now connected by means of T T′ to the inducing plate P; this may be designated the P system. No charge under this arrangement is possible in the system Q which is to earth, consequently the needle remains undisturbed.

The wire T′ is now disconnected, *b* raised to disconnect the Q system from earth; up to this point there is no deflection, but the instant that the P system is discharged to earth by pressing down the key *c* then there occurs a negative deflection; in order to decrease the leakage to a minimum the key *a* is raised so as to disconnect Q from the Leyden-jar.

In order to avoid waste of time, and disturbances of the readings by possible leakage by waiting for the needle to come to rest, the resting point was determined by means of a formula from two consecutive turning points.

The diagram fig. 15 represents the zero of the scale, the zero 17 of the readings, the first turning point A, the second turning point B, and the resting point R; 3 represents the third turning point, and 4 the fourth.

Fig. 15.



$$R = B + c(A - B)$$

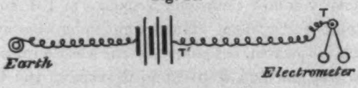
c is a factor determined once for all, by causing the needle to swing by means of an electric charge and then discharging; so that the subsequent swings are due solely to the torsion of the bifilar suspension. Four sets of observations were made and the needle allowed to come to rest at R in each series. These were very concordant, and c came out $\frac{1}{2\cdot92}=0\cdot3425$ by the formula $c=\frac{r}{1+r}$, where $1:r$ is the ratio of the length of one swing to the next, the swings being found to decrease very accurately in geometric progression. By waiting till the needle comes to rest, c may of course be determined directly, by means of the ratio in which any swing is divided by the observed resting point. Thus in fig. 16, AB : RB : : 1 : c. These two methods of determining c agreed perfectly.

The following results were obtained by making the observations on the plan just described.

TUBE 149 CO^2 (12 aluminium rings).

8540 cells. The full potential determined as in diagram fig. 16 was 251 divisions.

Fig. 16.



The positive pole of the battery was connected to No. 1 ring; the negative pole and No. 12 ring to earth, and each third ring in succession from 1 to 12 was connected with the electrometer.

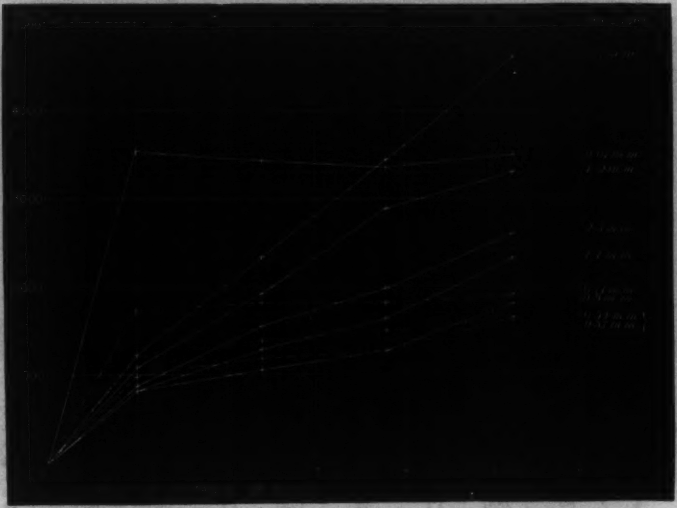
Ring.	Pressure 6·7 millimetres. Potential.			Pressure 4·2 millimetres. Potential.			Pressure 2·5 millimetres. Potential.			Pressure 1·4 millimetre. Potential.			Pressure 0·9 millimetre. Potential.		
	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.
1	136	4267	3·78	97	3301	3·03	76	2586	3·04	68	2314	2·83	53	1803	2·21
4	101	3437	2·80	85	2892	2·66	58	1973	2·32	48	1633	2·00	37	1259	1·54
7	68	2314	1·89	56	1905	1·75	45	1531	1·80	37	1259	1·54	31	1054	1·29
10	36	1225	1·00	32	1088	1·00	25	851	1·00	24	817	1·00	24	817	1·00

Ring.	Pressure 0·54 millimetre. Potential.*			Pressure 0·37 millimetre. Potential.			Pressure 0·14 millimetre. Potential.			Pressure 0·07 millimetre. Potential.			Distance between 12th and the following rings.		
	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.	Inches.	Centims.	Ratio.
1	49	1667	1·75	49	1667	1·40	56	1905	1·12	103	3504	0·99	22·25	57·1	5·24
4	37	1259	1·32	44	1497	1·26	51	1818	1·02	98	3334	0·94	16·20	41·1	3·81
7	35	1191	1·25	40	1361	1·14	51	1818	1·02	101	3437	0·97	10·20	25·9	2·40
10	28	953	1·00	35	1191	1·00	50	1701	1·00	104	3538	1·00	4·25	10·8	1·00

* Pressure of minimum resistance 0·54 millimetre.

The foregoing results are plotted in the diagram, fig. 17, where the abscissæ are the relative distances of the rings, as given in the last column of the above table, and the ordinates the potentials in numbers of cells.

Fig. 17.



TUBE 150 CO^2 (17 aluminium rings).

8540 cells; full potential 403 divisions.

The positive pole of the battery connected to No. 1 ring; the negative pole and the 17th ring to earth. Each ring in succession was connected to electrometer.

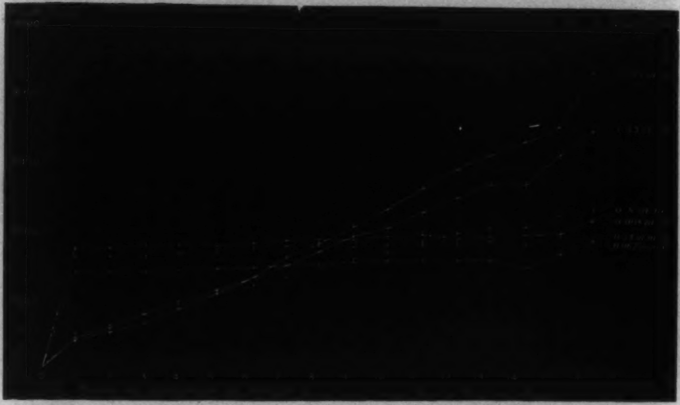
Ring.	Pressure 3·33 millimetres. Potential.			Pressure 1·33 millimetres. Potential.			Pressure 0·8 millimetre. Potential.			Pressure 0·34 millimetre.* Potential.		
	Divisions.	Cells.	Ratio.	Divisions.	Cells.	Ratio.	Divisions.	Cells.	Ratio.	Divisions.	Cells.	Ratio.
1	206	4366	9·8	165	3497	7·5	112	2373	4·5	90	1907	1·3
2	168	3560	8·0	149	3158	6·8	107	2268	4·3	80	1695	1·2
3	158	3349	7·5	128	2713	5·8	99	2098	4·0	70	1484	1·0
4	148	3137	7·0	128	2713	5·8	98	2077	3·9	76	1611	1·1
5	138	2925	6·6	119	2522	5·4	94	1992	3·8	76	1611	1·1
6	124	2628	5·9	109	2310	5·0	88	1865	3·5	75	1590	1·1
7	111	2358	5·2	98	2077	4·5	82	1738	3·3	75	1590	1·1
8	99	2098	4·7	92	1950	4·2	77	1632	3·1	74	1568	1·1
9	87	1844	4·1	82	1738	3·7	71	1505	2·8	73	1547	1·1
10	77	1632	3·7	72	1526	3·3	64	1356	2·6	72	1526	1·1
11	65	1377	3·1	65	1377	2·9	58	1229	2·3	70	1484	1·0
12	53	1123	2·5	55	1166	2·5	52	1103	2·1	69	1462	1·0
13	42	890	2·0	47	996	2·1	45	954	1·8	68	1441	1·0
14	32	678	1·5	38	805	1·7	38	805	1·5	67	1420	1·0
15	26	551	1·2	29	615	1·3	31	657	1·2	67	1420	1·0
16	21	445	1·0	22	466	1·0	25	530	1·0	67	1420	1·0
17	0	..	0·0	0	..	0·0	0	..	0·0	0	..	0·0

Ring.	Pressure 0·067 millimetre. Potential.			Pressure 0·008 millimetre. Potential.			Distance between 17th and the following rings.		
	Divisions.	Cells.	Ratio.	Divisions.	Cells.	Ratio.	Inches.	Centims.	Ratio.
1	90	1907	1·2	104	2204	1·2	32·10	81·5	16·44
2	93	1971	1·2	96	2034	1·2	30·10	76·4	15·41
3	87	1844	1·1	94	1992	1·1	28·20	71·6	14·44
4	89	1887	1·1	92	1950	1·1	26·02	66·1	13·34
5	87	1844	1·1	91	1929	1·1	24·15	61·3	12·37
6	86	1823	1·1	93	1971	1·1	22·05	56·0	11·30
7	86	1823	1·1	92	1950	1·1	20·00	50·6	10·24
8	85	1801	1·1	90	1907	1·1	18·00	45·7	9·22
9	86	1823	1·1	90	1907	1·1	16·10	40·9	8·24
10	85	1801	1·1	89	1887	1·1	14·12	35·8	7·24
11	83	1759	1·1	87	1844	1·0	12·12	30·8	6·22
12	82	1738	1·1	85	1801	1·0	10·02	25·4	5·13
13	79	1674	1·0	86	1823	1·0	7·92	20·1	4·06
14	79	1674	1·0	85	1801	1·0	5·90	15·0	3·03
15	78	1653	1·0	83	1759	1·0	3·90	9·9	2·00
16	78	1653	1·0	83	1759	1·0	1·95	4·9	1·00
17	0	..	0·0	0	..	0·0	..	..	..

* Pressure of minimum resistance 0·34 millimetre.

These results are shown in the diagram, fig. 18, in which the abscissæ are the relative distances of the rings, as given in the last column of the above table, and the ordinates the potentials in numbers of cells.

Fig. 18.



The following experiments were made in order to ascertain the effect produced on the potential of different parts of a vacuum tube connected at the ends with the opposite poles of an insulated battery when the centre of the tube was put in communication with earth, fig. 19.

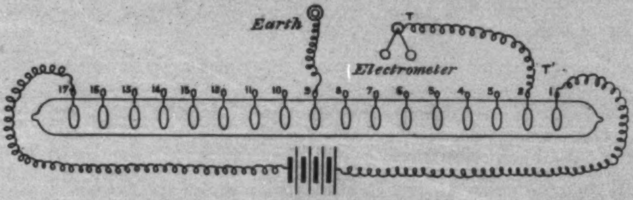
Tube 150. CO^2.

Battery insulated 8540 cells.

The positive pole was connected to No. 1 ring; the negative to No. 17 ring. The centre ring (No. 9) to earth, and each ring in succession connected with the electrometer. Pressure about 0·5 millimetre*. The deflection was positive between 1 and 9, and negative between 9 and 17.

The diagram, fig. 19, shows the arrangement of the apparatus. The wire T, T′, was connected at T′ to each ring in succession from No. 1 to No. 17.

Fig. 19.



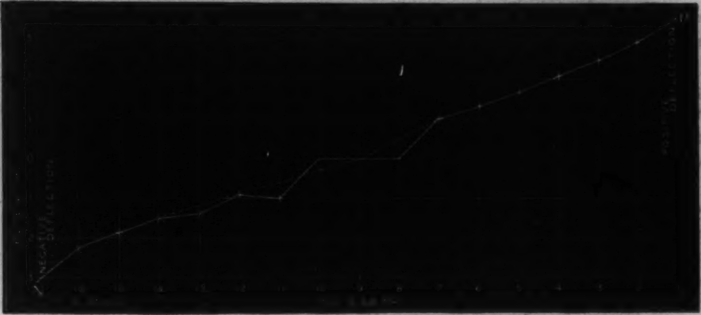
I.	Potential.		Distance from 9th ring.		VI.	Column $\frac{VI}{III}$.
Ring.	II. Divisions.	III. Ratio.	IV. In inches.	V. Centims.	Ratio of distances.	
1	+114	3·563	15·975	40·5	4·096	1·150
2	+ 93	2·907	14·075	36·0	3·608	1·242
3	+ 79	2·469	11·925	30·2	3·058	1·239
4	+ 66	2·063	10·050	25·5	2·577	1·253
5	+ 53	1·657	7·950	20·2	2·038	1·230
6	+ 42	1·312	5·900	15·0	1·513	1·153
7	+ 32	1·000	3·900	9·9	1·000	1·000
8	..	0·000	2·000	5·1	..	..
9	..	0·000	0·000	0·0	0·000	..
10	..	0·000	1·900	4·8	..	..
11	− 42	1·000	3·850	9·8	1·000	1·000
12	− 38	0·905	5·850	14·9	1·519	1·679
13	− 59	1·405	7·950	20·2	2·065	1·470
14	− 64	1·524	9·975	25·3	2·590	1·700
15	− 78	1·858	11·975	30·4	3·111	1·674
16	− 94	2·239	13·925	35·3	3·616	1·615
17	−132	3·144	15·875	40·3	4·123	1·312

---

* The tube not being attached to the pump connected with the McLeod gauge, the pressure could not be exactly determined.

The foregoing results are plotted down in fig. 20, in which abscissæ are the distances of the rings and the ordinates the potentials in scale divisions of the electrometer.

Fig. 20.



The following table contains the results of another experiment also with the opposite poles of the battery to opposite ends of the tube, and the centre ring No. 9 to earth. Fig. 21 represents the results graphically. Tube 150 CO_2, pressure 0·45 m.m., 4620 cells, full potential 227 divisions.

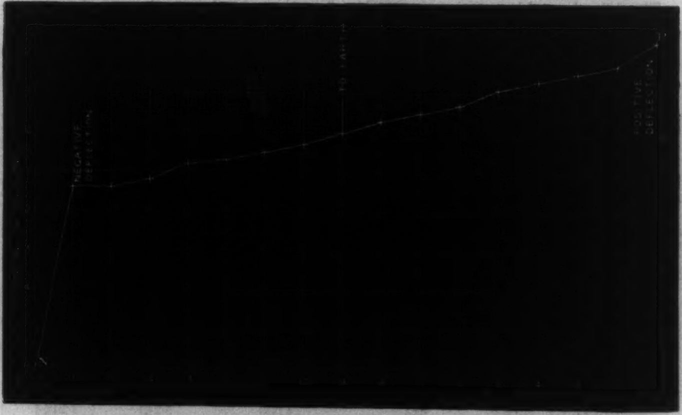
Ring.		Potential.			I.	II.	Column $\frac{II}{I}$.	
		Divisions.	Cells.		Ratio of potentials.	Ratio of distances.		
Positive	1	23+	468	468	7·767	7·987	1·028	Mean 1·25
	2	17+	346		5·666	7·037	1·242	
	3	15+	305		5·000	5·964	1·192	
	4	13+	264		4·333	5·024	1·160	
	5	11+	224		3·667	3·976	1·084	
	6	7+	142		2·333	2·950	1·264	
	7	5+	102		1·666	1·950	1·170	
	8	3+	61		1·000	1·000	1·000	
to earth	9	0	0		0·000	0·000	0·000	
	10	3−	61		1·000	1·000	1·000	
	11	5−	102		1·666	2·026	1·531	
	12	7−	142		2·333	3·079	1·319	
	13	8−	163		2·667	4·184	1·569	
	14	12−	244		4·000	5·249	1·312	
	15	14−	284		4·667	6·302	1·350	
	16	14−	284		4·667	7·328	1·570	
Negative	17	61−	1242	1242	20·330	8·354	0·411	
			Total	1710				

When the opposite poles of the battery were connected to the two end rings and the centre ring No. 9 to earth, the deflections, as we have before said, were all positive between 1 and 9, and all negative between 9 and 17; if the connexions with the battery were made previous to the connexion of 9 to earth, and a well-formed steady stratification produced, very little change occurred in it when 9 was connected by means of a key to earth; in fact only a slight one in those strata close to the earth ring.

The curves, more especially fig. 21, show that there is no disturbance of the potentials in consequence of the earth connexion in the centre of the tube, but that the whole curve is lifted or depressed so as to cut the axis at that point. The curve (fig. 22) brings out very forcibly how far greater is the obstacle to the passage of the discharge at the negative than at the positive electrode.

We have already called attention in Part III. of our researches to the far greater obstacle presented by the negative terminal to the passage of a discharge than occurs at the positive.* We therein described an experiment with a tube in which the negative terminal was a wire 19 inches long which became more and more illuminated as the current was gradually increased.

Fig. 21.



In order to bring into strong evidence the great resistance to the passage of electricity at the negative as compared to the positive terminal, the same ring was made positive and negative alternately.

---

* Phil. Trans. for 1880, vol. 171, Part I., p. 108 (separate copy, Part III., p. 202).

Tube 150. CO_2.

4640 cells at pressures 0·45 m.m. and 0·25 m.m.; in the first case battery full potential 242 divisions, in the second 213 divisions.

In the first series, at both pressures, the positive was connected with No. 1 ring; in the second, the negative was connected with No. 1 ring. No. 17 ring and the opposite pole of the battery to earth.

Ring.	Pressure 0·45 millimetre. Potential.						Pressure 0·25 millimetre. Potential.						Distance between 17th and the following rings.
	Positive to No. 1.			Negative to No. 1.			Positive to No. 1.			Negative to No. 1.			
	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.	Divs.	Cells.	Ratio.	Ratio.
1	85	1629	1·77	61	1169	10·16	82	1786	1·34	74	1612	12·34	16·44
3	78	1496	1·62	34	652	5·66	77	1677	1·26	12	261	2·00	14·44
5	73	1400	1·52	30	575	5·00	73	1590	1·20	21	457	3·50	12·37
7	68	1304	1·42	27	518	4·50	71	1546	1·16	10	218	1·67	10·24
9	62	1189	1·29	21	402	3·50	67	1460	1·10	16	348	2·67	8·24
11	58	1112	1·21	23	441	3·83	64	1394	1·05	21	457	3·50	6·22
13	52	997	1·09	14	268	2·33	59	1285	0·97	8	174	1·33	4·06
15	48	920	1·00	7	134	1·16	59	1285	0·97	6	131	1·00	2·00
16	48	920	1·00	6	115	1·00	61	1328	1·00	6	131	1·00	1·00
17	0	0	0·00	0	0	0·00	0	0	0·00	0	0	0·00	0·00

The results are shown in the diagram, fig. 22.

The foregoing experiments "show clearly," as Professor STOKES has pointed out to us, "that at high exhaustions nearly the whole of the energy is spent in the passage of the discharge between the gas and the negative electrode. It seems pretty clear that the electric potential energy is converted into kinetic energy.

"There appears to be no such difficulty as regards the positive. The increase of change of potential near the positive at moderate exhaustions seems fully accounted for by the contraction of the path of the discharge, as the electricity issues at first from little more than a mere point, and the path at first lies within an approximately conical boundary.

"The experiments bear in an important manner on the theoretical height of the aurora. It appears that at high exhaustions gases offer little obstacle to the passage of electricity; only there must be matter enough to carry it. On the whole the experiments tend to considerably increase the theoretical height, which accords with observation, so far as such observations can be trusted.

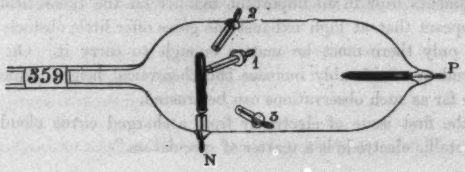
"How far the first issue of electricity from a charged cirrus cloud resembles the issue from a metallic electrode is a matter of speculation."

Fig. 22.

Electrical condition of a gas in a vacuum tube in the vicinity of the negative terminal.

The preceding experiments, in relation to potential at different parts of a column of gas, suggested the desirability of probing the electrical condition of a tube in the vicinity of the terminals, more especially the negative. Professor **Stokes** suggested that this might be conveniently done by means of wires fixed at different distances from it, provided the wires were covered with miniature glass tubes reaching nearly to their extremities. Accordingly a bulb was prepared of the form and construction represented half-size in fig. 23, in which P is a terminal in the shape of a point, to serve as the positive, N, another in the shape of a ring, to serve as the negative, both

Fig. 23.

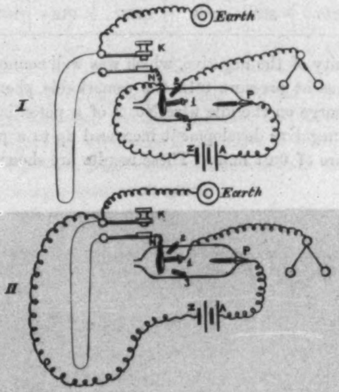


being of aluminium. Nos. 1, 2, and 3 are idle probing wires of platinum, covered with miniature glass tubes, except their extreme ends. The end of No. 1 is about 0·02, No. 2 0·2, and No. 3 0·6 inch from the ring.

In the following experiments variations were made: in one case the battery was insulated and its pole A connected with the point, and its pole Z with the ring; either a stout or a fine wire was then led from the ring, negative, to earth. At other times the battery was uninsulated, the pole A being connected to the point, and the pole Z with earth, and a stout or a fine wire led from the earth connexion to the ring. The stout wire, 0·06 inch diameter, was that ordinarily used in connecting the battery, the fine wire, 3 feet of platinum, 0·002 inch diameter, and having a resistance of 81 ohms at 19°·2 C.

Fig. 24, I. and II., shows the different arrangements.

Fig. 24.



In I. the battery is insulated, the silver end A being connected with the point, and the zinc Z with the ring; from the negative ring a stout wire is led to the lower portion of the key K, and the earth connexion is made with stout wire to the upper part of the key, so that in the position shown in the figure the communication to earth is through the fine wire, but when K is pressed down then the earth communication is through the stout wire.

II. shows the battery uninsulated, the silver end A being connected to the point, and the zinc Z to the upper part of the key. The ring is connected to earth by a stout wire, and also to the lower part of the key. In the position shown in the figure the discharge has to pass through the fine wire to earth, but when the key is pressed down it passes through the stout wire.

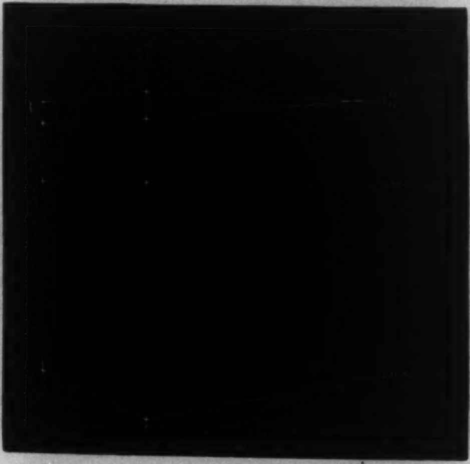
The following results were obtained with tube 359 air :—

Pressure 0·5 millimetre. Battery 1200 cells. Arrangement II. Stout wire. Potential, cells.					Pressure 0·18 millimetre. Battery 1200 cells. Arrangement II. Stout wire. Potential, cells.				
Tube.	No. 3.	No. 2.	No. 1.	Ring.	Tube.	No. 3.	No. 2.	No. 1.	Ring.
540	10+	40+	0	0	730	20+	50−	70−	0

Pressure 0·0335 millimetre. Battery 2400 cells. Arrangement II. Stout wire. Potential, cells.					Pressure 0·01 millimetre. Battery 5840 cells. Arrangement II. Stout wire. Potential, cells.				
Tube.	No. 3.	No. 2.	No. 1.	Ring.	Tube.	No. 3.	No. 2.	No. 1.	Ring.
496	273−	273−	273−	0	4627	912−	1068−	912−	0

So that in the vicinity of the negative, which was well connected to earth and gave no deflection, there was at pressure 0·18 the remarkable phenomenon of a development of a negative charge on the idle wire No. 2 of a potential equal to 50 cells, and on No. 1 of 70; this negative development increased up to a potential of as high as 1068 cells, at a pressure of 0·01 m.m. These results are shown in the curve (fig. 25).

Fig. 25.



Pressure 0·027 millimetre. Battery 5840 cells. Arrangement II.

Stout wire. Potential, cells.					Fine wire. Potential, cells.				
Tube.	No. 3.	No. 2.	No. 1.	Ring.	Tube.	No. 3.	No. 2.	No. 1.	Ring.
1794	478−	1196−	578−	0	..	120+	120+	100+	0

Pressure 0·027 millimetre. Battery 5840 cells. Arrangement II.

Stout wire. Potential, cells.					Fine wire. Potential, cells.				
Tube.	No. 3.	No. 2.	No. 1.	Ring.	Tube.	No. 3.	No. 2.	No. 1.	Ring.
1734	619−	619−	640−	0	3921	392−	62+	186+	0

The pressure by standing during a night fell to 0·017 m.m., some of the air had evidently become partly absorbed by the terminals, and 5840 cells would no longer pass. In some of the following experiments the inside of a Leyden-jar of the capacity of 0·0049 microfarad was sometimes made to communicate with the ring (negative), the exterior of the jar being connected to earth.

Pressure 0·017 millimetre. Battery 7040 cells. Arrangement II. Stout wire.

Potential, cells.

Tube.	No. 3.		No. 2.		No. 1.		Ring.
		With jar.		With jar.		With jar.	
5134	1040−	1040−	1256−	1018−	1560−	1387−	0
4325	815−	776−	873−	892−	853−	1106−	0

Pressure 0·017 millimetre. Battery 7040 cells. Arrangement II. Fine wire.

Potential, cells.

Tube.	No. 3.		No. 2.		No. 1.		Ring.
		With jar.		With jar.		With jar.	
5134	0	0	173+	108+	195−	195−	0

The signs + and − denote the name of the electrical charge at the idle wires, and it is seen that in many cases the charge is again negative, notwithstanding that the negative ring gives no deflection.

In the following experiments the inside of the Leyden-jar was in contact sometimes with the negative, at others with the positive terminal of the tube.

Pressure 0·017 millimetre. Battery 7040 cells. Arrangement II. Stout wire.

Potential, cells.

Tube.	No. 3.		No. 2.		No. 1.		Ring.
		Jar to P.		Jar to P.		Jar to P.	
4325	1086−	466+	931−	698+	1145−	252+	0

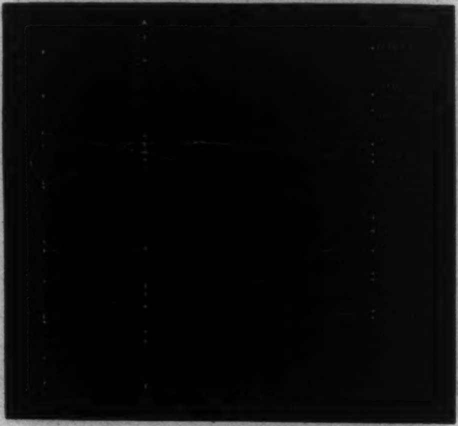
Pressure 0·017 millimetre. Battery 7040 cells. Arrangement II. Fine wire.

Potential, cells.

Tube.	No. 3.			No. 2.			No. 1.			Ring.
		Jar			Jar			Jar		
		To N.	To P.		To N.	To P.		To N.	To P.	
6874	358+	48+	787+	72+	0	859+	167−	453+	763+	0

These results are given in the curve (fig. 26).

Fig. 26.



In the following experiments the arrangement I. was employed, that is to say, the poles of an insulated battery were connected with the terminals of the tube, and an earth connexion made either by means of a stout or fine wire to the negative terminal.

Air was introduced, and at various pressures, with 2400 cells, the following results were obtained :—

Pressure 3·7 millimetres. Battery 2400 cells. Arrangement I. Potential, cells.					Pressure 1·7 millimetre. Battery 2400 cells. Arrangement I. Potential, cells.				
Tube. Stout or fine.	No. 3. Stout or fine.	No. 2. Stout or fine.	No. 1. Stout or fine.	Ring. Stout or fine.	Tube. Stout or fine.	No. 3. Stout or fine.	No. 2. Stout or fine.	No. 1. Stout or fine.	Ring. Stout or fine.
513+	47+	47+	47+	0	513+	466+	466+	466+	0

Pressure 0·18 millimetre. Battery 2400 cells. Arrangement I. Potential, cells.						Pressure 0·1 millimetre. Battery 2400 cells. Arrangement I., mean of six experiments. Potential, cells.				
Tube. Stout or fine.	No. 3. Stout or fine.	No. 2. Stout or fine.	No. 1.		Ring. Stout or fine.	Tube. Stout or fine.	No. 3. Stout or fine.	No. 2. Stout or fine.	No. 1. Stout or fine.	Ring. Stout or fine.
			Stout.	Fine.						
1235+	1119+	986+	116−	140+	0	1990+	1784+	1281+	384+	0

The connexion to earth made through a cork (0·5 inch diameter, and 0·5 inch long) saturated with water, and having a resistance of 4,300,000 ohms.

Pressure 0·1 millimetre. Battery 2400 cells. Arrangement I. Potential, cells.				
Tube.	No. 3.	No. 2.	No. 1.	Ring.
1179+	1420+	955+	367+	0

Cork introduced into circuit—

Pressure 0·1 millimetre. Battery 2400 cells. Arrangement II. Potential, cells.				
Tube.	No. 3.	No. 2.	No. 1.	Ring.
2400	1763	1616	441	2400

These results are shown in the curve (fig. 27).

Fig. 27.

Potential at the centre and periphery of a ring negative terminal.

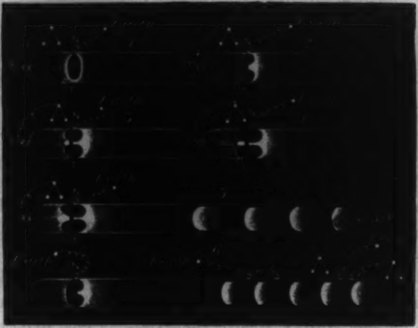
Everyone familiar with the appearance of a stratified discharge will have noticed, when the negative terminal is a ring, that as the exhaust proceeds a spindle of light approaches and at last protrudes through the interior of it, as shown in fig. 28, 5.

This spindle is thus a visible exponent of strong action among the molecules of the gas composing it, and it appeared to be of interest to probe its electrical condition. We therefore prepared a tube, No. 363, for this special object with an idle wire, surrounded by a minute glass tube, except its extremity, in the axis of the tube and projecting to a distance of $\frac{3}{8}$ of an inch (0·95 centim.) from the plane of the ring which was made negative.

The dimensions of the tube are:—Length, 15·5 inches (39·3 centims.), and 1·75 inches (4·44 centims.) in diameter, and the distance between the terminals, a point and a ring, 12 inches (30·5 centims).

A battery of 3600 cells was used, the terminal, in the shape of a point, was connected to the positive pole, and the ring and negative pole of the battery were both connected to earth. The gas used was carbonic anhydride. The full potential of the battery was found to be 313 divisions of the electrometer, that of the idle axial wire at a certain exhaust 142 divisions, equal to 1633 cells.

Fig. 28.



The exhaust was carried further, and it then required 6000 cells to produce a discharge. The tube potential was found to be equal to 2523 cells, and the idle wire, T, 2535 cells, or practically the same as the tube.

Another set of experiments was made with the same tube, and progressively greater and greater exhausts, consequently presenting different appearances of the luminosity at the negative ring as the exhaust was increased. These appearances are shown in fig. 28, Nos. 1, 2, 3, 4, 5, in which the idle wire, T, is connected with the electrometer.

		Divisions.	Ratio to tube potential = 1.
1. Idle wire,	T potential	48	= 0·52
	Tube „	92	
1. A little higher exhaust, T	„	57	= 0·60
	Tube „	95	
2.	T „	118	= 0·87
	Tube „	136	
2. A little higher exhaust, T	„	134	= 0·93
	Tube „	144	
3.	T „	143	= 0·90
	Tube „	158	
4.	T „	170	= 0·94
	Tube „	181	
5.	T „	163	= 0·95
	Tube „	173	

It is evident, therefore, that as the exhaust increases, and the luminous spindle becomes more developed, the potential of the idle wire, T, augments until it nearly or quite equals that of the whole tube.

In tube No. 363 there was no means of testing the potential on the outside of the negative ring under the same conditions as the centre, so that another tube, No. 364, was made in which an idle wire, T, was in the axis 0·25 inch (0·63 centim.) from the plane of the ring, and another, T′, 0·15 inch (0·38 centim.) from its periphery. The tube is 13½ inches (34·3 centims.) long, 1¾ inches (4·44 centims.) in diameter, and 9½ inches (24·1 centims.) between the terminals, and was charged with carbonic anhydride.

When 2400 cells were used, the tube potential was found to be 742 cells; the potential of the axial wire, T, was 158 cells, when that of the exterior wire, T′, was only 40 cells, so that the potential of the central wire, T, was $\frac{158}{40}=3{\cdot}9$ times that of the external wire T′. The potentials in relation to that of the whole tube equal 1, were found to be T wire =0·21, T′ =0·054.

Potential across a dark space and a stratum respectively.

At the suggestion of Professor STOKES, experiments were made to ascertain the potential across a dark space and also a stratum, several tubes being constructed for that object. The experiment is an extremely troublesome one, on several accounts; in the first place it is difficult to get a stratum or a space to fall exactly between a pair of idle wires, and although this may be frequently accomplished, even between the same pair, when there is a steady and slow onward motion of the strata, if the battery is left on for a time and the tube becomes gradually heated; yet even then it requires great dexterity to catch the precise moment at which to make contact with the electrometer. Part of the difficulties may possibly be due to the inherent nature of the discharge itself, which if a pulsating one of a very high order, may be caught at different phases at the instant of contact.

In tube No. 361 charged with carbonic anhydride, 32·5 inches (82·5 centims.) long, and 1·75 inches (4·44 centims.) in diameter, having two terminals, one a point, the other a ring, distant 28·25 inches (71·74 centims.), two idle glass-covered wires were fused into it. No. 1, 11·75 inches (29·84 centims.), and No. 2, 12·75 inches (32·38 centims.) from the plane of the ring which was made negative; the proper position of the idle wires was determined by that of the strata in a preliminary trial.

The battery used was 3600 cells, the negative pole and the ring terminal were connected to earth.

The tube potential was found to be =1945 cells.

When the electrometer was connected with :—

	Cells.
No. 1, touching convex side of a stratum, the potential was	= 1862
No. 2, " concave " " "	
At another pressure the tube potential	= 1784
No. 1, touching a dark space	= 1339
No. 2, " "	
No. 1, touching concave of stratum	= 1398
No. 2, " convex "	

So that when an idle wire either touched the convex or concave side of a stratum, or either side of a dark space, the potential was the same, and approached nearly that of the tube when tested at the positive terminal.

With the same tube when the two points were made to straddle a stratum or a space, one point, No. 2, connected with the electrometer, and the other, No. 1, to earth, the indications differed.

	Cells.	Stratum.	Space.
A stratum intervening, potential	= 282	= 1·32	= 1
A dark space, "	= 215		

Another series gave—

	Cells.	Stratum.	Space.
Stratum intervening, "	= 87	= 1·19	= 1
Dark space, "	= 73		

Another series gave results the reverse of this, namely, a greater potential when a dark space intervened, but it is possible that the connexion with the electrometer was not made precisely at the proper moment.

	Cells.		
Space . .	102	=	1·05
Stratum . .	97	=	1

Taking the mean of several other sets, the balance of the results is in favour of the potential being greatest when a stratum intervenes, for example:—

	Stratum.	Space.
	1·243	1
	1·327	1
	1·081	1
Mean	1·243	1

A series of experiments were made with tube No. 362 having a hydrogen charge; a battery of 3600 cells being used, which gave a current of 0·04686 ampère through it.

This tube has four idle wires *a*, *b*, *c*, *d*, as shown in fig. 28, 6, but only two were used, namely, *c* and *d*, 1 inch (2·54 centims.) apart; and a stratum or a space was made to intervene between them. The positive pole was connected to the terminal in the shape of a point, and the negative to the ring which was also connected to earth. The following are the results:—

		Divisions.		Cells.		Divisions.		Cells.
Tube potential	=	192		1443				
Stratum ,,		111			Space	98		
		137				59		
		84				115		
		132				78		
		133				115		
		129				69		
		74				72		
		146				69		
		102				141		
		132				142		
	Mean	118	=	887		96	=	722

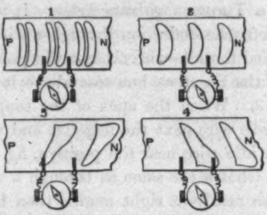
These figures may be taken as fairly representing the whole series of observations. $\frac{112}{98}$=1·229, which agrees well with the ratio before cited as that of the potential of a stratum to that of a space=1; and we think that it may be fairly assumed that the potential is really greater when a stratum is straddled than when a space is straddled.

Eddies in an electric discharge through a vacuum tube.

On testing the discharge between two idle wires distant $\frac{5}{8}$ inch (1·6 centim.) with a THOMSON galvanometer, the current was found sometimes to go in the reverse direction to that of the main current. In order to fix with certainty this phenomenon in one's mind the current was at first sent through a fine platinum wire 26 inches (66·04 centims.) long, and 0·002 inch (0·005 centim.) in diameter, leading wires from a THOMSON galvanometer were connected $\frac{1}{2}$ inch (1·27 centim.) apart with the middle of the wire, the deflection of the galvanometer to the right showed that the current was as anticipated in the same direction in this fraction as in the whole wire. The deflection through the wire was 162 divisions with $\frac{1}{999}$ shunt, $=161,200$ without shunt, $=\frac{75\cdot5 \text{ volts}}{1 \text{ megohm}}$ to the right. When a moistened thread was substituted for the fine wire the effect was the same. When, however, a vacuum tube was employed, then evidence was frequently obtained of a current in a contrary direction.

With tube No. 365, 21$\frac{3}{4}$ inches (55·25 centims.) long, with 3600 cells, a series of eleven pairs of beautiful double strata like those in Plate 16, fig. 3, Part III., were obtained, fig. 29, 1; these were perfectly steady. Two idle wires, 9$\frac{3}{4}$ inches (24·8 centims.) and 10 inches (25·4 centims.) distant from the positive end and embracing the seventh pair of strata, were connected with the THOMSON galvanometer,* when the following numbers were obtained :—

Fig. 29.



	With $\frac{1}{9}$ shunt.		Without shunt.
To left	50−	=	496−
To right	56+	=	559+
To left	50−	=	496−
,,	30−	=	298−
,,	140−	=	1389−
To right	143+	=	1419+

On introducing a resistance of 500,000 ohms in the current, a pink stratification of nineteen strata was obtained like that in Plate 16, fig. 4, Part III., fig. 30, 2. The

---

[*] The constant of this galvanometer, with the controlling magnet in the position used in the following experiments, is $C\,\frac{1 \text{ volt}}{1 \text{ megohm}}=2136$ divisions, or through 2136 ohms $\times 10^6=1$ division. The multiplier for the $\frac{1}{9}$th shunt $=9\cdot92$, that for the $\frac{1}{999}$th $=995\cdot3$.

idle wires embraced the eleventh stratum from the positive, and deflections were obtained as under with ⅑ shunt:—

	With ⅑ shunt.		Without shunt.
To left	180–	=	1785–
To right	170+	=	1686+
„	70+	=	694+
To left	204–	=	2023–[*]
To right	110+	=	1091+
„	140+	=	1386+
„	130+	=	1289+
„	30+	=	297+
„	15+	=	149+
To left	20–	=	198–

With tube No. 362 hydrogen charge and a battery of 2400 cells, the strata were tongue-shaped as in Part II.,[†] Plate 15, fig. 11; two touch points 1 inch (2·54 centims.) apart were connected with a THOMSON galvanometer. It was noticed that there was a strong deflection to the left (the deflection through a wire being to the right) when the base of a stratum touched the idle wire nearest the positive terminal and its apex pointed in the direction of the negative, but rose above it towards the opposite diameter of the tube, fig. 29, 3. When the apex of the tongue pointed in the reverse position so as to touch the idle wire next the negative and the base went to the other side of the tube above the idle wire near the positive, fig. 29, 4, then the deflection was in a contrary direction (that is the same as through a wire). When the tongues crossed the axis of the tube nearly at right angles, then there was an oscillation of the needle, first in one direction then in the other, according as the strata altered their position slightly with regard to the direction of the apex and base of the tongue.

The following are the readings without any shunt:—

140	left	–
20	right	+
15	left	–
210	right	+
200	„	+
165	„	+
150	„	+
210	left	–

Sometimes when a deflection took place in the same direction as the current through a wire, and had arrived at its maximum, then a slow oscillation was observed in the deflection, the needle moving backwards and forwards for about 20 divisions when the full deflexion was 290, or 0·068 of the total deflection.

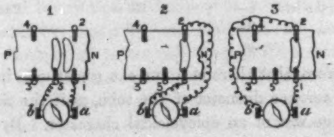
---

[*] Nearly equal to 1 volt through a megohm.

[†] Phil. Trans. for 1878, Vol. 169.

Another tube was made to test whether there is a current at right angles to the column of gas; namely No. 366, 21½ inches (54·61 centims.) long, and 1⅝ inches (4·1 centims.) in diameter, in it are sealed five idle wires, 1, 2, 3, 4, 5. No. 3 is 5½ inches (14 centims.) from the positive. Nos. 3, 5, 1 are all in a longitudinal line on the same side of the tube, 4 and 2 in line on the opposite side; 4 is diametrically opposite to 3, 2 diametrically opposite to 1. The tube with its wires is shown in fig. 30, 1, 2, 3; the opposite wires of the galvanometer are marked *a* and *b*.

Fig. 30.



The charge was hydrogen, and 2400 cells were used. In the first place the galvanometer was connected with two wires in a longitudinal direction, the galvanometer wire *b* to the idle wire 5, the galvanometer wire *a* to the idle wire 1; the idle wires at this time straddled both a stratum and a space. The deflection was to the right, amounting to:—

With ⅒ shunt.	Without shunt.
202+	2004+
117+	1161+
62+	615+
37+	367+
22+	218+
2+	20+
82+	813+
102+	1012+
132+	1309+

The wires of the galvanometer were now reversed, *a* to 5 and *b* to 1, the deflection was now to the left, but the galvanometer connexion having been reversed, the sign was the same as in the preceding.

With ⅒ shunt.	Without shunt.
98+	972+
68+	674+
83+	823+
68+	675+
58+	575+
48+	476+
38+	377+
118+	1170+

All these deflections are in the same direction as if the current went through a wire. The wires of the galvanometer were now connected, *b* to 1, *a* to 2, these being diametrically opposite, a stratum was touched at an opposite end of its diameter by each wire ; the readings were :—

With $\frac{1}{9}$ shunt.	Without shunt.	The current was from
To left 3−	30−	1 to 2
,, 8−	79−	,,

The wires were now reversed, *a* to 1 and *b* to 2, and the following observed :—

With $\frac{1}{9}$ shunt.	Without shunt.	The current was from
To the right 12+	119+	1 to 2
,, ,, 2+	20+	,,
To the left 8−	79−	2 to 1
,, ,, 3−	30−	,,
0	0	

It is evident, therefore, that there is a current sometimes in one direction, sometimes in the contrary, across a diameter of the tube, as if the motion of the molecules conveying the discharge was of an epicycloidal character. By way of comparison a tin-plate, 14½ inches (36·8 centims.) long and 5½ inches (14 centims.) wide, with circular ends, was made ; a connecting clamp was soldered to each end and two others across a central diameter. The direction of the current was ascertained when the poles of the battery were connected one to each end of the plate, and the opposite wires of the galvanometer also one to each end. Then the two clamps across a central diameter were connected alternately with the opposite ends of the galvanometer, the terminals remaining connected with the ends of the plate, but no deflections occurred even without a shunt.

One of the main objects of the experiments recorded in this paper was to endeavour to discover some of the obscure secrets of the electric discharge through gases. Although many more will undoubtedly have to be made before a theory can be formed which will account even for a few of the complex phenomena presented by this discharge, yet every onward step, however small, brings us nearer to the goal, and we shall consider ourselves well rewarded if we have advanced the frontier in the very smallest degree. We believe that what we have done has secured some advance, and rendered evident that electricity is always conveyed in gases by ponderable matter and not by the so-called ether ; moreover, that there are eddies in the discharge in a vacuum tube, and that it is possible that these eddies may be connected with the production of strata whose form would depend on the kind of eddy originally produced. This recalls the phenomena figured in Part III., Plate 8, fig. 34 ;* in this is seen an eddy of strata through small holes in a tube confining the main discharge.

We have much pleasure in thanking Professor STOKES for his many valuable suggestions, and for his kind advice generally, during the course of this investigation. To our chief assistant, Mr. JAMES FRAM, we are indebted for able and zealous co-operation, and we wish to place on record the excellent services of our junior assistant, Mr. ERNEST DAVIS. Mr. H. REYNOLDS has, as on former occasions, taken the photographs with his usual skill.

---

* Phil. Trans. for 1880, Vol. 171.

POSTSCRIPT.

(Added July 10th, 1883.)

Our battery now consists of 15,000 cells, all of the form in which the chloride of silver is fused into rods on a flattened silver wire.* On the occasion of a lecture given by one of us at the Royal Institution on January 21, 1881, 14,400 cells, partly of the rod form, partly of the chloride in powder form, were used; the length of the spark with this number between paraboloidal points was 0·7 inch (17·8 millims.), and between a point and disc 0·62 inch (15·7 millims.). It will be recollected that in Part I. of our researches,† we obtained with 11,000 cells between two points a spark 0·62 inch long, and between a point and disc one 0·47 inch long. It does not appear, therefore, that the law of the spark being as the square of the number of cells holds good beyond a certain number; the falling off may be in part due, however, to the failure of insulation as the potential is increased.

$$\frac{14400^2 \times 0{\cdot}62 \text{ inch}}{11000^2} = 1{\cdot}060 \text{ inch (27 millims.)}$$

$$\frac{14400^2 \times 0{\cdot}47 \text{ inch}}{11000^2} = 0{\cdot}806 \text{ inch (20 millims.)}$$

Since the removal of the battery from the Royal Institution we have not charged up the whole of it, as the experiments on which we have been engaged did not necessitate more than 11,000 cells.

We have recently (May 10–July 4) repeated the experiments on the question of the polarisation of the terminals on a discharge taking place in gases, and have obtained the same results as those already described;‡ they confirm, therefore, our previously expressed opinion,§ that the experiments point conclusively to the deduction that the small current, which is observed when the terminals of a vacuum tube (in which a discharge has taken place) are disconnected from the battery and instantaneously connected with a galvanometer, is due solely to a static charge and not to *chemical polarisation*.

---

* Phil. Trans., Part I., Vol. 169, 1878, p. 109, separate copy, p. 55.

† Ibid., p. 118, separate copy, p. 64.

‡ Proc. Roy. Soc., No. 205, 1880, pp. 563–572.

§ Ibid., p. 570.

INDEX TO PART IV.

PAGE
Air, striking distance in dry and moist, fig. 9 .. 483–484
Aurora, height of, figs. 1–3 .. 477–480
Column of gas, potentials at different nearly aliquot parts of, at various pressures, figs. 13–22 .. 489–499
Column of gas, evidence of a reversal of current in parts of it during a discharge, fig. 29 .. 510–512
Complex strata, fig. 12; Plate 35, fig. 9 .. 487
Dark negative space, actinically dark only by comparison with strata, Plate 36, fig. 21B .. 488–489
Deposit, mirror-like, during a discharge, fig. 8 .. 482
Discharge from two separate batteries through the same tube, first in the same and then in a contrary direction, fig. 10; Plate 35, figs. 1–6 .. 484–485
Discharge from two separate batteries through the same tube, crossing each other at right angles, fig. 11; Plate 35, fig. 10; Plate 36, figs. 15–20 .. 485–487
Discharge in large tubes, Plate 35, figs. 11–14 .. 488
Discharge in miniature tubes, figs. 4–6 .. 481–482
Eddies in an electric discharge through a vacuum tube, figs. 29–30 .. 510–514
Electrical condition of a gas in a vacuum tube in the vicinity of the negative terminal, figs. 23–27 500–505
Electrometer, modification of the mode of working with, Professor STOKES', figs. 13–15 .. 489–492
Electrometer, needle resting-point, determined from consecutive swings, fig. 15 .. 491
Luminous spindle, electrical condition of, fig. 28, 1, 2, 3, 4, 5 .. 506–508
Molecules, freedom of motion of .. 480–481
Negative terminal, electrical condition of a gas in the vicinity of, figs. 23–27 .. 500–505
Negative ring terminal, potential at the centre and periphery of, fig. 28 .. 506–508
Occlusion of gas by terminals, figs. 7–8 .. 482–483
Palladio-hydrogen volatile alloy, occlusion of, figs. 7–8 .. 482
Ponderable matter necessary for the transfer of electricity .. 480–481
Potential across a dark space and a stratum respectively, fig. 28, 6 .. 508–510
Potential at different nearly aliquot parts of a column of gas at various pressures, figs. 13–22 .. 498–499
Potential at the centre and periphery of negative ring terminal, fig. 28 .. 506–508
Potential, full, determination of, fig. 16 .. 492
Pressure of least resistance, dependent on the shape and dimensions of vessel, figs. 1, 2, 3 .. 477–481
Spark, length of, in dry and moist air, fig. 9 .. 483–484
Spindle of light protruding through negative ring terminal, electrical condition of, fig. 28, 1, 2, 3, 4, 5 .. 506–508
Strata, complex, fig. 12; Plate 35, fig. 9 .. 487
Strata produced by separate discharges in opposite directions in the same tube, Plate 35, figs. 1–6 484–485
Strata produced by separate discharges and crossing each other at right angles, fig. 11; Plate 35, fig. 10; Plate 36, figs. 15–20 .. 485–487
Stratum, apparent plasticity of the aggregate assemblage of molecules constituting it, Plate 36, fig. 17 .. 486
Stratum, threaded on the negative terminal, Plate 35, fig. 9 .. 487
Two batteries, mutual accommodation of, Plate 36, fig. 15 .. 486
Two separate currents in the same tube, first in the same and then in a contrary direction, fig. 10; Plate 35, figs. 1–6 .. 484–485

PLATES 35 AND 36, REFERENCES TO TEXT.

	PAGE
Plate 35, fig. 1	484
„ figs. 2–6	485
„ figs. 7–8	487
„ fig. 9	487
„ fig. 10	486
„ figs. 11–14	488
Plate 36, figs. 15–18	486
„ figs. 19–20	487
„ fig. 21	489

CURVES REPRESENTING TABLES, REFERENCES TO TEXT.

Fig. 17	492
„ 18	494
„ 20	496
„ 21	497
„ 22	499
„ 25	502
„ 26	503-504
„ 27	505

XIII. *On Electrical Motions in a Spherical Conductor.*

By **Horace Lamb**, *M.A., formerly Fellow of Trinity College, Cambridge, Professor of Mathematics in the University of Adelaide.*

Communicated by J. W. L. **Glaisher**, *M.A., F.R.S.*

Received March 14,—Read April 5, 1883.

This paper treats of the motions of electricity produced in a spherical conductor by any electric or magnetic operations outside it. The investigation was undertaken some time ago in illustration of Maxwell's theory of Electricity. This theory is so remarkable, more especially in the part which it assigns to dielectric media in the propagation of electromagnetic effects, that it seemed worth while to attack some problem in which all the details of the electrical processes could be submitted to calculation, although it was evident beforehand, from the researches of Helmholtz* and others, that the results (so far as they are peculiar to the theory) would be of far too subtle a character to admit of comparison with experiment. In studying the mathematical character of the problem above stated I was led to a certain system of formulæ which I have since utilised in two communications to the London Mathematical Society,† and which seem likely to be of use in a great variety of physical questions.

§ 1 consists mainly of a recital of the fundamental equations and of the conditions to be satisfied at the surface of a conductor. It is assumed, in the first instance, that the magnetic susceptibility of the conductor is zero.

In § 2 is introduced the assumption that all our functions vary as $e^{\lambda t}$, where t is the time, and λ a constant. It is pointed out that this assumption is sufficiently general. The fundamental equations are then put into a mathematically convenient form. Before, however, proceeding to apply these equations as they stand, I examine the effect of assuming that the velocity (v) of propagation of electromagnetic effects in the medium surrounding the conductor is practically infinite. This assumption, which has been made by all writers (including Maxwell himself) who have applied Maxwell's theory to ordinary electromagnetic phenomena, greatly simplifies the calculations without sensibly impairing the practical value of the results. If L stand for a linear dimension of the conductor and ρ for its specific resistance, it will appear in the sequel that when as in all practical cases λ is small compared with v/L, the error introduced by the assumption in question is of the order $\lambda\rho/v^2$. For any ordinary metallic conductor, and for any value of λ which can be appreciated experimentally, this fraction is excessively minute.

---

* Crelle, t. 72 (1870).

† "On the Oscillations of a Viscous Spheroid," Proc. L. M. S., Nov. 10, 1881; and "On the Vibrations of an Elastic Sphere," May 11, 1882.

In § 3 the solutions of our equations (on the assumption above indicated) are given in the form appropriate to our present problem. These solutions are of two distinct types. Those of the first type, which are much the more important from an experimental point of view, have (I find) been discussed, though by a different method, by Professor C. NIVEN in a paper recently published.[*] As the points to which attention has been directed are for the most part sufficiently distinct in the two investigations, I have allowed the corresponding portions of my paper to stand.

In § 4 I discuss the case of electric currents started anyhow in the sphere and left to themselves. The equation which gives the "moduli" of the natural modes of decay of the first type agrees with the result obtained by Professor NIVEN.

In § 5 is studied the case of induced currents. Since any disturbance in the field (however arbitrary) can be expressed, as regards the time, by a series of simple harmonic terms, it is sufficient to consider the case when the variations in the inducing system follow the simple harmonic law. This case has moreover acquired a special interest since the invention of the telephone.

The two extreme cases, when the period of the variation in the field is very large or very small in comparison with the time of decay of free currents in the sphere, are discussed in some detail.

In § 6 the case of a thin spherical *shell* is briefly examined.

I next proceed to investigate what modifications must be introduced into the methods and the results of the preceding sections when the substance of the sphere is susceptible of magnetisation. This occupies §§ 7, 8, 9, 10.

In the remaining sections of the paper I investigate the solution of our fundamental equations, taking account of the finite value of v. The corrections to our former results are of most interest in the solutions of the second type. Although the preceding theory, based on the assumption $v=\infty$, is sufficient for all purposes of comparison with experiment, there are certain processes of (at all events) theoretical interest of which it fails altogether to give an account, viz., all those cases in which any change in the superficial electrification of the sphere takes place. For the expression of these the solutions of the second type are appropriate. There is no difficulty in working out the requisite formulæ, but in the application to the case of *free* motion a difficulty of interpretation arises which is noticed in the proper place.

1. Let us suppose that we have one or more conductors at rest in an insulating

---

[*] Phil. Trans., 1882. The date of the paper is January, 1880.

medium. If F, G, H be the components of electromagnetic momentum, u, v, w those of electric current, at the point (x, y, z), we have on MAXWELL's theory

$$\left.\begin{aligned}\nabla^2\mathrm{F}&=-4\pi u\\ \nabla^2\mathrm{G}&=-4\pi v\\ \nabla^2\mathrm{H}&=-4\pi w\end{aligned}\right\} \quad \ldots\ldots\ldots \quad (1)$$

and

$$\frac{d\mathrm{F}}{dx}+\frac{d\mathrm{G}}{dy}+\frac{d\mathrm{H}}{dz}=0 \quad \ldots\ldots\ldots \quad (2),$$

where ∇^2 stands for $d^2/dx^2+d^2/dy^2+d^2/dz^2$. These equations hold good in conductors and insulators alike, provided that (as we shall assume for the present) the magnetic permeability in neither case differs sensibly from unity.

In the conductors we have, if ρ be the specific resistance,

$$\left.\begin{aligned}\rho u&=-\frac{d\phi}{dx}-\frac{d\mathrm{F}}{dt}\\ \rho v&=-\frac{d\phi}{dy}-\frac{d\mathrm{G}}{dt}\\ \rho w&=-\frac{d\phi}{dz}-\frac{d\mathrm{H}}{dt}\end{aligned}\right\} \quad \ldots\ldots\ldots \quad (3).$$

The expressions on the right-hand side of (3) are the components of electromotive force, ϕ being a function which, in the case of *steady* motion of electricity, is known by the name of the "electric potential."*

In the dielectric we have, if f, g, h be the components of electric displacement, and $1/v^2$ the specific inductive capacity, measured (like all our quantities) on the electromagnetic system,

$$\left.\begin{aligned}4\pi v^2 f&=-\frac{d\phi}{dx}-\frac{d\mathrm{F}}{dt}\\ 4\pi v^2 g&=-\frac{d\phi}{dy}-\frac{d\mathrm{G}}{dt}\\ 4\pi v^2 h&=-\frac{d\phi}{dz}-\frac{d\mathrm{H}}{dt}\end{aligned}\right\} \quad \ldots\ldots\ldots \quad (4).$$

v is the velocity of propagation of electromagnetic effects in the dielectric medium. If this be air, v also denotes the number of electrostatic units in one electromagnetic unit of electricity.

The conditions to be satisfied at the boundary of a conductor are that F, G, H and their first derivatives must be continuous. This follows at once from the expressions for F, G, H in terms of the electric currents in the field, viz.,

---

* In other cases, as will be seen, this name is less appropriate.

$$\left.\begin{aligned} \mathrm{F}&=\iiint\frac{u'}{r}dx'dy'dz' \\ \mathrm{G}&=\iiint\frac{v'}{r}dx'dy'dz' \\ \mathrm{H}&=\iiint\frac{w'}{r}dx'dy'dz' \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5),$$

where r denotes the distance from the element $dx'dy'dz'$ to the point (x, y, z) at which the values of F, G, H are required. Hence if a, b, c be the components of magnetic induction, viz.,

$$\left.\begin{aligned} a&=\frac{d\mathrm{H}}{dy}-\frac{d\mathrm{G}}{dz} \\ b&=\frac{d\mathrm{F}}{dz}-\frac{d\mathrm{H}}{dx} \\ c&=\frac{d\mathrm{G}}{dx}-\frac{d\mathrm{F}}{dy} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6),$$

these quantities will be continuous at the surface of a conductor. Conversely we may show that if F, G, H, a, b, c be continuous then the first derivatives of F, G, H will all be continuous. For this it is sufficient to prove that their derivatives in the direction of the normal will be continuous. If l, m, n be the direction-cosines of the normal, we have

$$\begin{aligned} l\frac{d\mathrm{F}}{dx}+m\frac{d\mathrm{F}}{dy}+n\frac{d\mathrm{F}}{dz}&=l\frac{d\mathrm{F}}{dx}+m\frac{d\mathrm{G}}{dx}+n\frac{d\mathrm{H}}{dx}+nb-mc \\ &=\left(m\frac{d\mathrm{G}}{dx}-l\frac{d\mathrm{G}}{dy}\right)-\left(l\frac{d\mathrm{H}}{dz}-n\frac{d\mathrm{H}}{dx}\right)+nb-mc \quad . \quad . \quad . \quad (7), \end{aligned}$$

by (2), and it is easily seen from geometrical considerations that the continuity of G implies the continuity of $(m.d\mathrm{G}/dx-l.d\mathrm{G}/dy)$, and so on. Hence if F, G, H, a, b, c be continuous, the first member of (7), and the corresponding expressions for the normal derivatives of G and H, are continuous.

From this point the letters u, v, w will be used to denote solely the components of current *in the conductors*. The components of current in the dielectric are $\dot{f}, \dot{g}, \dot{h}$.

The general solenoidal conditions to be satisfied by u, v, w and f, g, h, viz.,

$$\frac{du}{dx}+\frac{dv}{dy}+\frac{dw}{dz}=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8),$$

and

$$\frac{d}{dt}\left(\frac{df}{dx}+\frac{dg}{dy}+\frac{dh}{dz}\right)=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (9),$$

require, by (3) and (4),

$$\nabla^2\phi=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (10),$$

in the conductors, and

$$\nabla^2\frac{d\phi}{dt}=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (11),$$

in the dielectric. The superficial solenoidal condition

$$lu+mv+nw=l\frac{df}{dt}+m\frac{dg}{dt}+n\frac{dh}{dt}$$

requires, by (1), the continuity of

$$l\nabla^2\mathrm{F}+m\nabla^2\mathrm{G}+n\nabla^2\mathrm{H},$$

i.e., of

$$\left(n\frac{da}{dy}-m\frac{da}{dz}\right)+\left(l\frac{db}{dz}-m\frac{da}{dz}\right)+\left(m\frac{dc}{dx}-l\frac{dc}{dy}\right);$$

but this is implied in the continuity of a, b, c.

If $d\nu'$, $d\nu''$ be elements of a normal to the surface of a conductor, on the inside and outside respectively, we find from (3) and (4), taking account of the continuity of F, G, H,

$$-\left(\frac{d\phi}{d\nu'}+\frac{d\phi}{d\nu''}\right)=4\pi v^2(lf+mg+nh)-\rho(lu+mv+nw);$$

or, if σ denote the surface density of electricity,

$$-\left(\frac{d\phi}{d\nu'}+\frac{d\phi}{d\nu''}\right)-4\pi v^2\sigma-\rho\frac{d\sigma}{dt} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (12).$$

Hence it is only when the currents are *steady* that the relation between ϕ and the free electricity in the field is the same as in electrostatics.*

If T be the kinetic and V the potential energy of the field, we have

$$\mathrm{T}=\tfrac{1}{2}\iiint(\mathrm{F}u+\mathrm{G}v+\mathrm{H}w)\,dxdydz$$
$$+\tfrac{1}{2}\iiint(\mathrm{F}\dot{f}+\mathrm{G}\dot{g}+\mathrm{H}\dot{h})\,d\xi d\eta d\zeta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (13),$$

$$\mathrm{V}=2\pi v^2\iiint(f^2+g^2+h^2)\,d\xi d\eta d\zeta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (14),$$

---

* This peculiarity of Maxwell's theory has been pointed out by C. Niven, *loc. cit.*

where, for the moment, the coordinates x, y, z refer to the conductors, and ξ, η, ζ to the dielectric. Let us form the equation of energy for the case where disturbances produced anyhow in the field are left to themselves.

We have

$$\begin{aligned}\frac{d\mathrm{T}}{dt}&=\tfrac{1}{2}\iiint(\dot{\mathrm{F}}u+\dot{\mathrm{F}}u+\&c.)\,dxdydz\\&\quad+\tfrac{1}{2}\iiint(\dot{\mathrm{F}}\dot{f}+\dot{\mathrm{F}}f+\&c.)\,d\xi d\eta d\zeta\\&=\iiint(\dot{\mathrm{F}}u+\dot{\mathrm{G}}v+\dot{\mathrm{H}}w)\,dxdydz\\&\quad+\iiint(\dot{\mathrm{F}}\dot{f}+\dot{\mathrm{G}}\dot{g}+\dot{\mathrm{H}}\dot{h})\,d\xi d\eta d\zeta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)^*\end{aligned}$$

Substituting the values of $\dot{\mathrm{F}}$, $\dot{\mathrm{G}}$, $\dot{\mathrm{H}}$ from (3) and (4), we find

$$\begin{aligned}\frac{d\mathrm{T}}{dt}&=-\iiint\rho(u^2+v^2+w^2)\,dxdydz\\&\quad-4\pi v^2\iiint(f\dot{f}+g\dot{g}+h\dot{h})\,d\xi d\eta d\zeta\\&\quad-\iiint\left(u\frac{d\phi}{dx}+v\frac{d\phi}{dy}+w\frac{d\phi}{dz}\right)dxdydz\\&\quad-\iiint\left(\dot{f}\frac{d\phi}{d\xi}+\dot{g}\frac{d\phi}{d\eta}+\dot{h}\frac{d\phi}{d\zeta}\right)d\xi d\eta d\zeta\end{aligned}$$

The last two integrals disappear in virtue of the solenoidal conditions satisfied by the flow of electricity.† Hence

$$\frac{d}{dt}(\mathrm{T}+\mathrm{W})=-\iiint\rho(u^2+v^2+w^2)\,d\xi d\eta d\zeta \quad . \quad . \quad . \quad . \quad . \quad . \quad (16).$$

This expresses that the electrical energy lost is equivalent to the heat generated in the conductors according to JOULE'S law.

2. Now let us suppose that F, G, H, &c., all vary as $e^{\lambda t}$. The electrical motions in the conductors and in the surrounding dielectric may be of two kinds, *free* and *forced*. In the various modes of free motion the corresponding values of λ are real and negative. In the case of forced motion the disturbing force at any point of the field may, by FOURIER'S (double-integral) theorem, be expanded, as regards the time, in a series of periodic terms. The effects of these can then be investigated separately and afterwards superposed. The value of λ corresponding to any one term is $\lambda=2\pi ip$, where p is the frequency, and $i=\sqrt{-1}$.

---

* This may be deduced from (1) by GREEN'S Theorem. It is a particular case of THOMSON and TAIT, § 313 (*f*).

† MAXWELL'S 'Electricity,' § 100*a*.

On the above assumption, (2) become

$$\rho u=-\frac{d\phi}{dx}-\lambda F, \text{ \&c., \&c.} \quad \ldots \ldots \ldots \quad (17),$$

whence eliminating u, v, w by means of (1) we obtain as the equations to be satisfied in the interior of a conductor

$$\left.\begin{aligned}(\nabla^2+k^2)F&=-\frac{k^2}{\lambda}\frac{d\phi}{dx}\\(\nabla^2+k^2)G&=-\frac{k^2}{\lambda}\frac{d\phi}{dy}\\(\nabla^2+k^2)H&=-\frac{k^2}{\lambda}\frac{d\phi}{dz}\end{aligned}\right\} \quad \ldots \ldots \ldots \quad (18)$$

and

$$\frac{dF}{dx}+\frac{dG}{dy}+\frac{dH}{dz}=0 \quad \ldots \ldots \ldots \quad (19),$$

where

$$k^2=-\frac{4\pi\lambda}{\rho} \quad \ldots \ldots \ldots \quad (20).$$

In the dielectric we have

$$\nabla^2 F=-4\pi\frac{df}{dt}=-4\pi\lambda f, \text{ \&c., \&c.}$$

$$4\pi v^2 f=-\frac{d\phi}{dx}-\lambda F, \text{ \&c., \&c.}$$

Eliminating f, g, h we obtain

$$\left.\begin{aligned}(\nabla^2+j^2)F&=-\frac{j^2}{\lambda}\frac{d\phi}{dx}\\(\nabla^2+j^2)G&=-\frac{j^2}{\lambda}\frac{d\phi}{dy}\\(\nabla^2+j^2)H&=-\frac{j^2}{\lambda}\frac{d\phi}{dz}\end{aligned}\right\} \quad \ldots \ldots \ldots \quad (21),$$

with

$$\frac{dF}{dx}+\frac{dG}{dy}+\frac{dH}{dz}=0 \quad \ldots \ldots \ldots \quad (22),$$

where

$$j^2=-\frac{\lambda^2}{v^2} \quad \ldots \ldots \ldots \quad (23).$$

So far our equations are exact. But it appears from various physical analogies (more especially in Acoustics), and it will be verified in the course of this paper, that when the dimensions of the conductors are small compared with j^{-1} the phenomena are sensibly the same as if j were $=0$. Now, in air, $v=3\times10^{10}$ [C.G.S.], whence $j^{-1}=v/i\lambda=3\times10^{10}/i\lambda$. Since λ is proportional to the rapidity of the electrical motions it appears that in all practical cases j^{-1} is very large. We will therefore assume for the present $j=0$, which comes to the same thing as assuming that the velocity of propagation of electromagnetic effects in the dielectric medium is practically infinite. The equations to be satisfied in the neighbourhood of the conductors then are

$$\nabla^2 F=0, \quad \nabla^2 G=0, \quad \nabla^2 H=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (24)$$

$$\frac{dF}{dx}+\frac{dG}{dy}+\frac{dH}{dz}=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25).$$

Since $l\nabla^2 F+m\nabla^2 G+n\nabla^2 H$ must be continuous at the surfaces of the conductors it appears at once that on the present assumption we shall have, at those surfaces,

$$lu+mv+nw=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26).$$

3. Proceeding now to the special problem of this paper, viz., the case of a solid spherical conductor surrounded by air, let us take the origin of coördinates at the centre of the sphere, and let r denote the distance of any point from the origin. It may be shown, as in the papers on the "Oscillations of a Viscous Spheroid," &c., already referred to, that the solutions of the equations (18), (19), and (24), (25) are of two distinct types, which are quite independent of one another.

First Type. We have

In the conductor:

$$\left.\begin{aligned} F&=\psi_n(kr)\left(y\frac{d}{dz}-z\frac{d}{dy}\right)\chi_n \\ G&=\psi_n(kr)\left(z\frac{d}{dx}-x\frac{d}{dz}\right)\chi_n \\ H&=\psi_n(kr)\left(x\frac{d}{dy}-y\frac{d}{dx}\right)\chi_n \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (27),$$

where χ_n is a solid harmonic of positive integral degree n, and the function ψ_n is defined by

$$\psi_n(\zeta)=1-\frac{\zeta^2}{2.2n+3}+\frac{\zeta^4}{2.4.2n+3.2n+5}-, \text{ \&c.}$$

$$=(-)^n 3.5 \ldots 2n+1.\left(\frac{d}{\zeta d\zeta}\right)^n\frac{\sin\zeta}{\zeta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (28),$$

from either of which forms we readily deduce

$$\psi_n'(\zeta)=-\frac{\zeta}{2n+3}\,\psi_{n+1}(\zeta) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (29),$$

$$\psi_n(\zeta)+\frac{\zeta}{2n+1}\,\psi_n'(\zeta)=\psi_{n-1}(\zeta) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (30),$$

$$\psi_n(\zeta)-\psi_{n-1}(\zeta)=\frac{\zeta^2}{2n+1.2n+3}\,\psi_{n+1}(\zeta) \quad . \quad . \quad . \quad . \quad . \quad . \quad (31),$$

The equations (27) constitute the complete solution (of the first type) of (18) and (19) subject to the condition of finiteness at the origin. In the absence of this restriction we should have to add to the right-hand sides similar terms in which n is replaced by $-n-1$.[*]

In the space surrounding the conductor we have

$$\left.\begin{aligned} F&=\left(y\frac{d}{dz}-z\frac{d}{dy}\right)(X_n+X_{-n-1}) \\ G&=\left(z\frac{d}{dx}-x\frac{d}{dz}\right)(X_n+X_{-n-1}) \\ H&=\left(x\frac{d}{dy}-y\frac{d}{dx}\right)(X_n+X_{-n-1}) \end{aligned}\right\} \quad . \; . \; . \; . \; . \; . \; . \; . \tag{32}$$

where X_n, X_{-n-1} are solid harmonics of the algebraical degrees indicated by the suffixes.

Since the values (27) of F, G, H make $(\nabla^2+k^2)\,F=0$, &c., &c., it follows by (1) that the components of current inside the sphere are

$$\left.\begin{aligned} u&=\frac{k^2}{4\pi}\psi_n(kr)\left(y\frac{d}{dz}-z\frac{d}{dy}\right)\chi_n \\ v&=\frac{k^2}{4\pi}\psi_n(kr)\left(z\frac{d}{dx}-x\frac{d}{dz}\right)\chi_n \\ w&=\frac{k^2}{4\pi}\psi_n(kr)\left(x\frac{d}{dy}-y\frac{d}{dx}\right)\chi_n \end{aligned}\right\} \quad . \; . \; . \; . \; . \; . \; . \; . \tag{33}$$

The flow of electricity is everywhere perpendicular to the radius vector, and hence $\phi=\text{const.}$, inside and outside the sphere.

From (27) and (32) we derive :—

Inside the sphere :

$$\left.\begin{aligned} a&=-\left\{(n+1)\psi_{n-1}(kr)\frac{d\chi_n}{dx}-n\frac{k^2r^{2n+3}}{2n+1.2n+3}\psi_{n+1}(kr)\frac{d}{dx}\chi_n r^{-2n-1}\right\} \\ b&=-\left\{(n+1)\psi_{n-1}(kr)\frac{d\chi_n}{dy}-n\frac{k^2r^{2n+3}}{2n+1.2n+3}\psi_{n+1}(kr)\frac{d}{dy}\chi_n r^{-2n-1}\right\} \\ c&=-\left\{(n+1)\psi_{n-1}(kr)\frac{d\chi_n}{dz}-n\frac{k^2r^{2n+3}}{2n+1.2n+3}\psi_{n+1}(kr)\frac{d}{dz}\chi_n r^{-2n-1}\right\} \end{aligned}\right\} \quad . \; . \tag*{(34)†}$$

---

[*] These terms would be required in treating the case of a hollow spherical shell.

[†] These formulæ make

$$xa+yb+zc=-n.n+1.\psi_n(kr).\chi_n$$

Outside:

$$\left.\begin{aligned} a&=-(n+1)\frac{dX_n}{dx}+n\frac{dX_{-n-1}}{dx}\\ b&=-(n+1)\frac{dX_n}{dy}+n\frac{dX_{-n-1}}{dy}\\ c&=-(n+1)\frac{dX_n}{dz}+n\frac{dX_{-n-1}}{dz}\end{aligned}\right\}\quad . \ . \ . \ . \ . \ . \ . \ . \quad (35).$$

In deducing (34) we have made use of (29), (30), and of the known formula

$$x\chi_n=\frac{r^2}{2n+1}\left(\frac{d\chi_n}{dx}-r^{2n+1}\frac{d}{dx}\chi_n r^{-2n-1}\right)\quad . \ . \ . \ . \ . \ . \ . \quad (36).$$

We have now to apply the conditions to be satisfied at the surface of the sphere. If R be the radius, the continuity of F, G, H requires

$$\psi_n(k\mathrm{R}).\chi_n=\mathrm{X}_n+\mathrm{X}_{-n-1}\quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (37).$$

The continuity of a, b, c requires

$$\psi_{n-1}(k\mathrm{R}).\chi_n=\mathrm{X}_n\quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (38),^*$$

with another condition which is, however, implied in (37) and (38). We must bear in mind that in these equations r is supposed put $=\mathrm{R}$ throughout; so that χ_n, X_n, X_{-n-1} are now *surface* harmonics, of order n.

Second type. We have

Inside the sphere:

$$\phi=\phi_n\quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (39)$$

$$\left.\begin{aligned} \mathrm{F}&=-\frac{1}{\lambda}\frac{d\phi_n}{dx}+(n+1)\psi_{n-1}(kr)\frac{d\omega_n}{dx}-n\frac{k^2r^{2n+3}}{2n+1.2n+3}\psi_{n+1}(kr)\frac{d}{dx}\omega_n r^{-2n-1}\\ \mathrm{G}&=-\frac{1}{\lambda}\frac{d\phi_n}{dy}+(n+1)\psi_{n-1}(kr)\frac{d\omega_n}{dy}-n\frac{k^2r^{2n+3}}{2n+1.2n+3}\psi_{n+1}(kr)\frac{d}{dy}\omega_n r^{-2n-1}\\ \mathrm{H}&=-\frac{1}{\lambda}\frac{d\phi_n}{dz}+(n+1)\psi_{n-1}(kr)\frac{d\omega_n}{dz}-n\frac{k^2r^{2n+3}}{2n+1.2n+3}\psi_{n+1}(kr)\frac{d}{dz}\omega_n r^{-2n-1}\end{aligned}\right\}\quad . \ . \quad (40).^\dagger$$

---

* The rigorous proof of these, and of similar inferences in the sequel, may be conducted as in § 4 of the paper "On the Vibrations of an Elastic Sphere" already cited.

† These may also be written

$$\mathrm{F}=-\frac{1}{\lambda}\frac{d\phi_n}{dx}+(2n+1)\psi_{n-1}(kr)\frac{d\omega_n}{dx}-n\frac{d}{dx}\left\{\psi_n(kr)\omega_n\right\},\ \&c.$$

Outside:

$$\phi=\Phi_n+\Phi_{-n-1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (41).$$

$$\left.\begin{aligned} \mathrm{F}&=\frac{d\Omega_n}{dx}+\frac{d\Omega_{-n-1}}{dx} \\ \mathrm{G}&=\frac{d\Omega_n}{dy}+\frac{d\Omega_{-n-1}}{dy} \\ \mathrm{H}&=\frac{d\Omega_n}{dz}+\frac{d\Omega_{n-1}}{dz} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (42).$$

Here ϕ_n, Φ_n, Φ_{-n-1}, ω_n, Ω_n, Ω_{-n-1}, are solid harmonics of the algebraical degrees indicated.

These formulæ give

Inside:

$$\left.\begin{aligned} a&=-k^2\psi_n(kr)\left(y\frac{d}{dz}-z\frac{d}{dy}\right)\omega_n \\ b&=-k^2\psi_n(kr)\left(z\frac{d}{dx}-x\frac{d}{dz}\right)\omega_n \\ c&=-k^2\psi_n(kr)\left(x\frac{d}{dy}-y\frac{d}{dx}\right)\omega_n \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (43);$$

Outside:

$$a=0,\ b=0,\ c=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (44).$$

The sort of reciprocal relation between the formulæ (27) and (34) on the one hand, and (40) and (43) on the other, is very remarkable.

The continuity of F, G, H at the surface of the sphere implies two relations which we shall not require; whilst that of a, b, c involves

$$\psi_n(k\mathrm{R}).\omega_n=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (45).$$

This result follows also from (26), since

$$\begin{aligned} xu+yv+zw&=-\frac{1}{4\pi}(x\nabla^2\mathrm{F}+y\nabla^2\mathrm{G}+z\nabla^2\mathrm{H}) \\ &=\frac{k^2}{4\pi}.n(n+1)\psi_n(kr).\omega_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (46). \end{aligned}$$

4. From this point we must discuss separately the cases of free and forced motion, respectively. First let us take that of *free motion*. We assume that (no matter how) electric currents have been started in the sphere and then left to themselves.

First Type. The equations (24) must now hold not merely in the space immediately surrounding the sphere but right away to infinity. Hence we must have, in (32), $X_n=0$; and thence, by (37),

$$\psi_{n-1}(kR)=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (47).$$

The roots of this equation in kR are all real. For the case $n=1$ we have

$$kR/\pi=1,\ 2,\ 3,\ \&c.$$

When $n=2$,

$$kR/\pi=1{\cdot}4303,\ 2{\cdot}4590,\ 3{\cdot}4709,\ \&c. \quad . \quad . \quad . \quad . \quad . \quad . \quad (48).$$

When $n=3$,

$$kR/\pi=1{\cdot}8346,\ 2{\cdot}8950,\ 3{\cdot}9225,\ \&c. \quad . \quad . \quad . \quad . \quad . \quad . \quad (49).$$

When the value of k for any particular mode is known, the corresponding value of λ is given by (20). If τ denote the modulus of decay, *i.e.*, the time in which the currents fall to $1/e$ of their original strength, we have

$$\tau=-\lambda^{-1}=\frac{4}{\pi}.\left(\frac{kR}{\pi}\right)^{-2}.\frac{R^2}{\rho} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (50).$$

For any given mode τ is proportional to the square of the radius, and inversely proportional to the specific resistance; a result which may easily be obtained otherwise, by the method of "dimensions."

For a sphere of copper [$\rho=1642$, C.G.S.] the modulus of the slowest mode of decay is

$$\tau={\cdot}000775R^2 \text{ second,}$$

the unit of R being the centimetre. For a copper sphere, of the size of the earth [$R=6{\cdot}37\times10^8$] the corresponding value of τ is very nearly 10,000,000 years.

As regards the nature of the various modes we may observe that the lines of flow of electricity inside the sphere are the intersections of the spheres $r=$const. with the cones $\chi_n/r^n=$const.; in other words, they are the contour lines of the harmonics χ_n on a series of spherical surfaces concentric with the origin. The intensity of the current at any point is proportional to $\psi_n(kr).d\chi_n/de$, when de is an elementary angle at the centre of the sphere in a plane perpendicular to the line of flow passing through the point in question. The direction of the flow changes sign as we cross either the spheres for which $\psi_n(kr)=0$, or the cones for which $d\chi_n/de=0$. The components of the magnetic induction at points outside the sphere are, by (35)

$$\left.\begin{aligned} a&=nR^{2n+1}\psi_n(kR)\frac{d}{dx}\chi_n r^{-2n-1}\\ b&=nR^{2n+1}\psi_n(kR)\frac{d}{dy}\chi_n r^{-2n-1}\\ c&=nR^{2n+1}\psi_n(kR)\frac{d}{dz}\chi_n r^{-2n-1}\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (51).$$

The simplest and most important case is when $n=1$. This may easily be examined by making $\chi_1=x$. The lines of motion are then all circles having the axis of x as a common axis.

Second Type. It follows from (45) that we must now have

$$\psi_n(k\mathrm{R})=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (52).$$

In the cases $n=1$, $n=2$, the first few roots of this equation are given by (48), (49), respectively. The values of the modulus of decay corresponding to the various values of k are to be found from (50). In the most persistent mode of the present type the value of τ for a sphere of copper is

$$\tau=\cdot000379\ \mathrm{R}^2 \text{ second.}$$

As regards the nature of the motion inside the sphere we remark in the first place that since the radial flow is zero at the surface the electric currents form closed circuits. The flow at any point may be resolved into two components, one along, the other at right angles to, the radius vector. The radial component is

$$\frac{k^2}{4\pi}n.n+1.\psi_n(kr).\frac{\omega_n}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (53).$$

The second or transversal component is perpendicular to that cone of the series $\omega_n/r^n=$ const. which passes through the point in question; and its amount is

$$\frac{k^2}{4\pi}\{kr\psi'_n(kr)+(n+1)\psi_n(kr)\}\frac{d\omega_n}{rd\epsilon} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (54),$$

where $d\epsilon$ denotes as before an elementary angle at the centre of the sphere in a plane perpendicular to the above-mentioned cone.

When the harmonic ω_n is *zonal*, having the axis of x (say) as axis, the nature of the motion can be very simply expressed by means of a stream-function Ψ. The motion then takes place in a series of planes through the axis of x and is the same in each such plane. If u, $\mathfrak{v}$ be the components of current parallel and perpendicular to x, viz., $\mathfrak{v}=(yv+zw)/\varpi$, where $\varpi=\sqrt{(y^2+z^2)}$, we have

$$u=\frac{1}{\varpi}\frac{d\Psi}{d\varpi},\ \mathfrak{v}=-\frac{1}{\varpi}\frac{d\Psi}{dx} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (55),$$

where $2\pi\Psi$ is the total flux through the circle whose coordinates are (x, ϖ). Integrating (53) over the segment of the sphere of radius $r=\sqrt{(x^2+\varpi^2)}$ bounded by this circle we find

$$\Psi=\frac{k^3}{4\pi}.n.n+1.r\psi_n(kr)\int_0^\theta \omega_n \sin\theta d\theta$$

$$=-\frac{k^3}{4\pi}\psi_n(kr)\varpi\frac{d\omega_n}{d\theta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (56).$$

Here θ denotes the colatitude (viz., $\varpi=r\sin\theta$), and ω_n is supposed expressed in terms of r, θ. The integration is effected by means of the differential equation of zonal harmonics. The most interesting case is when $n=1$. Writing $\omega_1=r\cos\theta$, we have

$$\Psi=\frac{k^3\varpi^2}{4\pi}\psi_1(kr).$$

The forms of the lines of flow ($\Psi=$ const.) corresponding to a series of equidistant values of Ψ are shown in the figure. The different systems of lines of flow are separated by the spheres for which $\psi_1(kr)=0$. The drawing includes the first two of these. In the most persistent mode the inner sphere must be taken to represent the boundary of the conductor; in the next mode the second sphere must be taken; and so on.

It appears from (44) that the currents in the sphere exercise no magnetic action in the external space. Conversely no motions of the present type can be originated by any electromagnetic operations outside the sphere. It will be shown further on that both these statements require qualification when we take account of the finite value of v.

By combining in the proper way solutions of the two types we can represent the decay of any system of currents arbitrarily given in the sphere. The determination of the harmonics χ_n, ω_n in terms of the initial circumstances, although interesting mathematically, would occupy too much space to be given in full here. It may suffice to remark that if u, v, w be any three functions satisfying the solenoidal condition (8), and if $\xi=dw/dy-dv/dz$, &c., &c., then the values of u, v, w are completely determinate throughout any spherical region having its centre at the origin when we know the values of $xu+yv+zw$ and of $x\xi+y\eta+z\zeta$ throughout that region. This is most readily seen from hydrodynamical considerations. The problem then resolves itself into the identification of the given initial values of these expressions with those which result from our formulæ, viz.,

$$xu+yv+zw=\Sigma\Sigma\frac{k^2}{4\pi}.n.n+1.\psi_n(kr)\omega_n \quad . \quad . \quad . \quad . \quad . \quad . \quad (56\text{A}),$$

and

$$x\xi+y\eta+z\zeta=-\Sigma\Sigma\frac{k^2}{4\pi}n.n+1.\psi_n(kr)\chi_n \quad . \quad . \quad . \quad . \quad . \quad . \quad (56\text{B}).$$

The summations here embrace all integral values of n and all admissible values of k. In (56A) these are given by $\psi_n(k\text{R})=0$, and in (56B) by $\psi_{n-1}(k\text{R})=0$. The identification can be effected by known methods.

5. Let us next proceed to consider the currents induced in the sphere by operations outside it; and for simplicity let us suppose that the changes in the field are periodic and follow the simple harmonic law. The value of λ is now prescribed, viz., it $=2\pi ip$, where p is the frequency. Hence, by (20),

$$k^2=-8\pi^2 ip/\rho,$$

and

$$k=(1-\iota)q \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (57),$$

provided

$$q^2=4\pi^2 p/\rho \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (58).$$

Since all our formulæ involve only even powers of q there is no loss of generality in taking q always positive.

From (45) we see that $\omega_n=0$, so that we have to deal exclusively with solutions of the *first type*. The complete solution of the problem is then given by the equations (27) and (32) in which the values of χ_n, X_{-n-1} in terms of X_n are to be obtained from the surface-conditions (37) and (38), viz., we have

$$\chi_n=\frac{1}{\psi_{n-1}(k\text{R})}\text{X}_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (59),$$

$$\text{X}_{-n-1}=\left\{\frac{\psi_n(k\text{R})}{\psi_{-n-1}(k\text{R})}-1\right\}\frac{\text{R}^{2n+1}}{r^{2n+1}}\text{X}_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (60).$$

The values of the functions X_n are to be found as follows. It is easily seen that if a_0, b_0, c_0 be the components of the magnetic field due to the inducing system alone, the expression $xa_0+yb_0+zc_0$ must satisfy the equation

$$\nabla^2(xa_0+yb_0+zc_0)=0$$

at all points outside the inducing system, and vanish at the origin. Hence it must admit of expansion in a series of solid harmonics of positive integral degrees, say

$$xa_0+yb_0+zc_0=\Sigma_1^{\infty}\Theta_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (61).$$

But it appears from (35) that we must have

$$xa_0+yb_0+zc_0=-\Sigma_1^{\infty}n.n+1.X_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (62).$$

Comparing with (61) we find

$$X_n=-\frac{1}{n.n+1}\Theta_n.$$

For instance, let the magnetic field due to the inducing system be sensibly uniform in the neighbourhood of the sphere, say

$$a_0=I,\ b_0=0,\ c_0=0.$$

We find

$$X_1=-\tfrac{1}{2}Ix;\ X_2=X_3=\&c.=0.$$

The formulæ (33) for the currents in the sphere then become

$$\left.\begin{aligned} u&=0\\ v&=-D\psi_1(kr).z\\ w&=\ \ D\psi_1(kr).y \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (63),$$

where

$$D=\frac{k^2I}{8\pi\psi_0(kR)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (64);$$

and the disturbance (a_1, b_1, c_1) in the magnetic field, due to these currents, is given by

$$\left.\begin{aligned} a_1&=E\frac{d}{dx}\frac{x}{r^3}\\ b_1&=E\frac{d}{dy}\frac{x}{r^3}\\ c_1&=E\frac{d}{dz}\frac{x}{r^3} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (65),$$

provided

$$\mathrm{E}=-\frac{\mathrm{IR}^3}{2}\left\{\frac{\psi_1(k\mathrm{R})}{\psi_0(k\mathrm{R})}-1\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (66).$$

For the full interpretation of our formulæ it would be necessary to disentangle the real and the imaginary parts, and to discard one or the other. The results would be very complicated, even for the simplest harmonic constituent ($n=1$). There are certain cases, however, in which we can use methods of approximation, and so deduce the results of interest without much difficulty.

Thus, in the first place, let us suppose that the changes in the field are comparatively slow; more precisely, let the frequency p be very small compared with ρ/R^2. Since $k\mathrm{R}$ is then a small quantity, the expressions for the currents in the sphere are approximately,

$$\left.\begin{aligned} u&=-\frac{2\pi ip}{\rho}\left(y\frac{d}{dz}-z\frac{d}{dy}\right)\mathrm{X}_n\\ v&=-\frac{2\pi ip}{\rho}\left(z\frac{d}{dx}-x\frac{d}{dz}\right)\mathrm{X}_n\\ w&=-\frac{2\pi ip}{\rho}\left(x\frac{d}{dy}-y\frac{d}{dx}\right)\mathrm{X}_n \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (67).$$

This is the result which we should have obtained by neglecting *ab initio* the mutual influence of the currents in the sphere. The disturbance in the field due to these currents is given by

$$\left.\begin{aligned} a_1&=\mathrm{J}\frac{d}{dx}\mathrm{X}_n r^{-2n-1}\\ b_1&=\mathrm{J}\frac{d}{dy}\mathrm{X}_n r^{-2n-1}\\ c_1&=\mathrm{J}\frac{d}{dz}\mathrm{X}_n r^{-2n-1} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (68)$$

where

$$\mathrm{J}=\frac{-8\pi^2 inp\mathrm{R}^{2n+3}}{2n+1.2n+3.\rho} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (69).$$

For spheres of the same size the disturbance is *cæteris paribus* proportional to the specific conductivity.

Next let us examine the other extreme case, where the frequency p is large compared with ρ/R^2, and consequently $k\mathrm{R}$ is a large number. When ζ is large, the formula (28) becomes, approximately,

$$\psi_n(\zeta)=(-)^n.3.5\ldots 2n+1.\frac{\sin\left(\zeta+n\dfrac{\pi}{2}\right)}{\zeta^{n+1}}.$$

Writing $\zeta = kr = (1-i)qr$, and keeping only the most important term, we find

$$\psi_n(kr) = (-)^n.3.5\ldots 2n+1.\frac{e^{qr}.e^{i\left(qr+n\frac{\pi}{2}\right)}}{2i(kr)^{n+1}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (70).$$

Hence the factor

$$\frac{k^2}{4\pi}\frac{\psi_n(kr)}{\psi_{n-1}(k\mathrm{R})},$$

which occurs in the expressions for the induced currents, becomes, after several reductions,

$$-\frac{(2n+1)q}{2\sqrt{2\pi\mathrm{R}}}.\left(\frac{\mathrm{R}}{r}\right)^{n+1}.e^{q(r-\mathrm{R})+i\left\{q(r-\mathrm{R})+\frac{\pi}{4}\right\}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (71).$$

It appears from this that the disturbance inside the sphere consists of a series of waves propagated inwards from the surface with rapidly decreasing amplitude. Thus at a depth equal to the wave-length (ν, say), the amplitude is only 1/535 of what it is at the surface. The currents are therefore almost entirely confined to a superficial stratum of thickness comparable with ν. It appears from (58) that ν, $=2\pi/q$, $=\sqrt{(\rho/p)}$. As a numerical example let $\rho=1642$ (copper), $p=4000$; we find

$$\nu = {\cdot}64 \text{ centimetre.}$$

The condition of the applicability of our approximation is that $2\pi\mathrm{R}$ must be large in comparison with ν.*

Since, by (70), $\psi_n(k\mathrm{R})/\psi_{n-1}(k\mathrm{R})$ is of the order $1/k\mathrm{R}$, it appears from (60) and (38) that the disturbance in the field caused by the currents in the sphere is given by

$$\left.\begin{aligned} a_1 &= -n\mathrm{R}^{2n+1}\frac{d}{dx}\mathrm{X}_n r^{-2n-1} \\ b_1 &= -n\mathrm{R}^{2n+1}\frac{d}{dy}\mathrm{X}_n r^{-2n-1} \\ c_1 &= -n\mathrm{R}^{2n+1}\frac{d}{dz}\mathrm{X}_n r^{-2n-1} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (72).$$

The magnitude of the disturbance depends therefore on the size of the sphere, but is independent of the conductivity, so long as the fundamental condition of our approximation is satisfied. The reason of this is not far to seek. The greater the conductivity the greater will be the intensity of the currents at the surface of the sphere, but the more rapid will be the rate of diminution as we pass inwards; and it is easily seen from (71) that one cause will exactly compensate the other.

---

* The above results enable us to estimate what ought to be the thickness of a sheet of a given metal in order that it should act as a screen against a periodic electromagnetic action of given frequency. See the paper by Lord RAYLEIGH, cited below.

In fact, if we write

$$u'=\int^{R} u\,dr,\quad v'=\int^{R} v\,dr,\quad w'=\int^{R} w\,dr,$$

where the lower limit is taken at such a depth that the currents there are insensible, we readily find that the currents are approximately equivalent to an infinitely thin spherical *current sheet* of radius R, the components of the current at any point of the sheet being given by

$$\left.\begin{aligned} u'&=-\frac{2n+1}{4\pi R}\left(y\frac{d}{dz}-z\frac{d}{dy}\right)X_n\\ v'&=-\frac{2n+1}{4\pi R}\left(z\frac{d}{dx}-x\frac{d}{dz}\right)X_n\\ w'&=-\frac{2n+1}{4\pi R}\left(x\frac{d}{dy}-y\frac{d}{dx}\right)X_n \end{aligned}\right\} \quad . \; . \; . \; . \; . \; . \quad (73).^{*}$$

6. The foregoing methods can be readily adapted to the case of a shell bounded by two concentric spherical surfaces. The most interesting case is when the shell is infinitely thin. The free motions of the second type then decay with infinite rapidity, and there are no forced motions of this type. Hence we have practically to deal only with solutions of the first type. The theory of these has been given by Professor NIVEN, but for the sake of completeness it is here discussed from the point of view of the present paper.

Let u', v', w' be the components of the total current at any point of the shell, and let $\rho'=\rho/\delta$, where δ is the thickness of the shell. Then if all our functions vary as $e^{\lambda t}$ we shall have

$$\rho'u'=-\lambda F,\quad \rho'v'=-\lambda G,\quad \rho'w'=-\lambda H \quad . \; . \; . \; . \; . \quad (74).$$

In the hollow space inside the shell

$$\left.\begin{aligned} F&=\left(y\frac{d}{dz}-z\frac{d}{dy}\right)\chi_n\\ G&=\left(z\frac{d}{dx}-x\frac{d}{dz}\right)\chi_n\\ H&=\left(x\frac{d}{dy}-y\frac{d}{dx}\right)\chi_n \end{aligned}\right\} \quad . \; . \; . \; . \; . \; . \; . \quad (75),^{\dagger}$$

whilst (32) hold for the external space. The functions F, G, H must vary continually as we cross the shell, so that

$$\chi_n=X_n+X_{-n-1} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (76),$$

at the surface.

---

[*] The conclusions of this section have an obvious bearing on the results obtained by Professor D. E. HUGHES in his experiments with the Induction Balance (Proc. Roy. Soc., May 15, 1879).

[†] It is here assumed that the inducing system, if any, is situate in the space external to the shell.

The first derivatives of F, G, H are, however, discontinuous, viz., if $d\nu'$, $d\nu''$ be elements of the normal drawn inwards and outwards respectively, we must have

$$\left.\begin{aligned}\frac{d\mathrm{F}}{d\nu'}+\frac{d\mathrm{F}}{d\nu''}&=-4\pi u'\\ \frac{d\mathrm{G}}{d\nu'}+\frac{d\mathrm{G}}{d\nu''}&=-4\pi v'\\ \frac{d\mathrm{H}}{d\nu'}+\frac{d\mathrm{H}}{d\nu''}&=-4\pi w'\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (77),$$

which equations now replace (1). Hence, and from (74) we deduce

$$-n\chi_n+n\mathrm{X}_n-(n+1)\mathrm{X}_{-n-1}=\frac{4\pi\mathrm{R}\lambda}{\rho'}\chi_n \quad . \quad . \quad . \quad . \quad . \quad . \quad (78),$$

when $r=\mathrm{R}$, the radius of the shell.

In free motion $\mathrm{X}_n=0$, and thence

$$\tau=-\lambda^{-1}=\frac{4\pi\mathrm{R}}{(2n+1)\rho'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (79).$$

In the case of currents induced by a system external to the shell, we find

$$\chi_n=\frac{1}{1+\lambda\tau}\mathrm{X}_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (80),$$

and

$$\mathrm{X}_{-n-1}=-\frac{\lambda\tau}{1+\lambda\tau}\mathrm{X}_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (81),$$

when τ has the value (79). The value of X_n can be found as before when the nature of the inducing system is known. Writing $\lambda=2\pi ip$ we see from (80) that if the period of the disturbance be small compared with τ the shell will almost completely shelter the enclosed region from the electromagnetic action of the external system.*

The case where the inducing system is inside the shell may be treated in a similar manner. We have to introduce a function χ_{-n-1} for the internal space, whilst X_n is zero.

7. When the magnetic permeability μ of the substance of the conductor differs sensibly from unity, the processes of the foregoing articles require some modification. The equations (1) must then be replaced by

$$\left.\begin{aligned}\nabla^2\mathrm{F}&=-4\pi\mu u\\ \nabla^2\mathrm{G}&=-4\pi\mu v\\ \nabla^2\mathrm{H}&=-4\pi\mu w\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (82),$$

---

* See Lord RAYLEIGH, Phil. Mag., May, 1882, p. 344.

whilst (2) and (3) are unaltered. Hence the fundamental equations (18), (19) of our method retain the same form, provided

$$k^2=-\frac{4\pi\mu\lambda}{\rho} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (83).$$

The distribution of the induced magnetization in the conductor will be solenoidal. Hence if A, B, C be the components of this distribution, the corresponding parts of F, G, H will be

$$\frac{dN}{dy}-\frac{dM}{dz},\ \frac{dL}{dz}-\frac{dN}{dx},\ \frac{dM}{dx}-\frac{dL}{dy},$$

respectively, where

$$L=\iiint\frac{A}{r}\,dxdydz,\ M=\iiint\frac{B}{r}\,dxdydz,\ N=\iiint\frac{C}{r}\,dxdydz.$$

The integrations are supposed to extend throughout the magnetized substance, and r denotes the distance between the element $dxdydz$ and the point for which the values of L, M, N are required. Hence F, G, H are continuous at the surface, but their first derivatives, and consequently a, b, c, will be discontinuous. Let us distinguish the values of a, b, c just inside and just outside the conductor by the accents $'$ and $''$, respectively. Then the parts of a', b', c' due to the induced magnetisation are

$$-\mu\frac{dV}{dx},\ -\mu\frac{dV}{dy},\ -\mu\frac{dV}{dz},$$

and those of a'', b'', c'' are

$$-\frac{dV}{dx},\ -\frac{dV}{dy},\ -\frac{dV}{dz},$$

where V is the potential of free magnetism, viz.:

$$V=\iint(lA+mB+nC)\frac{dS}{r},$$

dS denoting an element of the surface of the body, and l, m, n the direction-cosines of the outwardly directed normal to dS, and the integration being taken over the surface of the conductor. Hence

$$a''-\frac{a'}{\mu}=4\pi l(lA+mB+nC),\ \&c.;$$

or, since $4\pi\mu A=(\mu-1)a'$, &c.,

$$\left.\begin{aligned}a'+(\mu-1)\,l\,(la'+mb'+nc')&=\mu a''\\ b'+(\mu-1)m(la'+mb'+nc')&=\mu b''\\ c'+(\mu-1)\,n\,(la'+mb'+nc')&=\mu c''\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (84).$$

We notice that these conditions give

$$la'+mb'+nc'=la''+mb''+nc'' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (85),$$

as ought to be the case. In fact (85) is implied in the continuity of F, G, H.

8. Proceeding now to the case of a spherical conductor, let the origin be taken at the centre, and let r be the radius vector of any point. Let us begin with the solutions of the *First Type*, the formulæ for which are given by (27), (32), (34), (35). The continuity of F, G, H gives as before

$$\psi_n(k\mathrm{R}).\chi_n=\mathrm{X}_n+\mathrm{X}_{-n-1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (86)$$

at the surface ($r=\mathrm{R}$). In applying (84) we remark that, at the surface,

$$la'+mb'+nc'=-\frac{n.n+1}{\mathrm{R}}\psi_n(k\mathrm{R}).\chi_n,$$

and hence that

$$l(la'+mb'+nc')=-\frac{n.n+1}{\mathrm{R}^2}\psi_n(k\mathrm{R}).x\chi_n,$$

$$=-\frac{n.n+1}{2n+1}\psi_n(k\mathrm{R})\left(\frac{d\chi_n}{dx}-\mathrm{R}^{2n+1}\frac{d}{dx}\chi_n r^{-2n-1}\right),$$

by (36). Hence (84) give

$$\left\{\psi_{n-1}(k\mathrm{R})+\frac{n}{2n+1}(\mu-1)\psi_n(k\mathrm{R})\right\}\chi_n=\mu\mathrm{X}_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (87),$$

with another condition which may however be shown to be included in (86) and (87).

The formulæ for the solutions of the *Second Type* are given in (40), (42), (43), (44). The surface conditions (84) yield

$$\psi_n(k\mathrm{R}).\omega_n=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (88).$$

9. In the case of *free* currents of the first type we have $\mathrm{X}_n=0$, and the equation to determine k is

$$\psi_{n-1}(k\mathrm{R})+\frac{n}{2n+1}(\mu-1)\psi_n(k\mathrm{R})=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (89).$$

When, as in iron, μ is a very large number, we have, as a first approximation,

$$\psi_n(k\mathrm{R})=0.$$

If $k\mathrm{R}=\vartheta$ be a solution of this, a second approximation is

$$k\mathrm{R}=\left\{1-\frac{1}{n(\mu-1)}\right\}\vartheta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (90).$$

When the values of $k\mathrm{R}$ have been found, the corresponding values of the modulus of decay are given by

$$\tau=\frac{4}{\pi}\left(\frac{k\mathrm{R}}{\pi}\right)^{-2}\frac{\mu\mathrm{R}^2}{\rho} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (91).$$

In iron we have $\mu=403$ (THALÉN), $\rho=9827$ C. G. S. The lowest root of (89), in the case $n=1$, is then $k\mathrm{R}=1{\cdot}4268\pi$, and the corresponding value of τ is

$$\tau={\cdot}0256\mathrm{R}^2.$$

The duration of the free currents is very much greater than in a non-magnetizable sphere of the same size and of equal conductivity. For an iron ball one foot in diameter the above value of τ is six seconds. For an iron globe of the size of the earth it would be 330,000,000 years.

The magnetic susceptibility of the substance has the effect of modifying the character, as well as the duration, of the natural modes of decay. Inside the sphere we have

$$la+mb+nc=-\frac{n.\overline{n+1}}{\mathrm{R}}.\psi_n(kr)\chi_n,$$

Since, by (89), this is almost zero at the surface, the lines of magnetic induction inside the sphere are for the most part closed curves. Their forms, in the first two modes of the class $n=1$, are given by the figure of § 4. The surface of the conductor is not, however, in these two respective modes, now represented by the two spherical surfaces there shown, but rather by two concentric spherical surfaces of radii smaller (for the case of iron) by about the four hundredth part.

For the free currents of the second type we have, by (88),

$$\psi_n(k\mathrm{R})=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (92).$$

The natural modes of decay are exactly the same as when $\mu=1$, but the persistency is in each case greater in the ratio of $\mu:1$; viz., the values of τ corresponding to the various roots of (92) are given by (91).

10. In the case of *induced* currents caused by a periodic variation in the magnetic field the value of X_n is to be found in the same manner as in § 5; and χ_n, X_{-n-1} are then determined by (86) and (87). If p be the frequency,

$$k=(1-i)q$$

where now

$$q^2=4\pi^2\mu p/\rho \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (93).$$

Let us examine first the case where $k\mathrm{R}$ is small. We then have, at the surface,

$$\chi_n=\frac{\overline{2n+1}.\mu}{n\mu+n+1}\mathrm{X}_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (94),$$

$$X_{-n-1}=\frac{(n+1)(\mu-1)}{n\mu+n+1}X_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (95),$$

approximately. The currents in the sphere are then given by

$$u=-\frac{2\pi ip}{\rho}\frac{2n+1.\mu^2}{n\mu+n+1}\left(y\frac{d}{dz}-z\frac{d}{dy}\right)X_n,\ v=\&c.,\ w=\&c. \quad . \quad . \quad . \quad . \quad (96).$$

The principal part of the disturbance in the field, due to the presence of the sphere, is given by

$$a_1=\frac{n(n+1)(\mu-1)}{n\mu+n+1}\frac{d}{dx}\frac{R^{2n+1}}{r^{2n+1}}X_n,\ b_1=\&c.,\ c_1=\&c. \quad . \quad . \quad . \quad . \quad . \quad (97).$$

These terms express the effect of the induced magnetization of the sphere. The effect of the induced currents is (under the circumstances supposed) small in comparison.

Next let us take the case of kR large. It is to be noticed that owing to the occurrence of the factor μ in (93) this condition is satisfied by very much smaller values of the frequency than the case of a non-magnetizable substance. We then have

$$\frac{k^2}{4\pi}\psi_n(kr)\chi_n=\frac{k^2\mu}{4\pi}\cdot\frac{2n+1.\psi_n(kr)}{2n+1.\psi_{n-1}(kR)+(\mu-1)n\psi_n(kR)}X_n.$$

The factor of X_n is by (70)

$$=\frac{2n+1}{4\pi}\cdot\frac{k^2\mu}{n(\mu-1)+ikR}\cdot\left(\frac{R}{r}\right)^{n+1}\cdot e^{q(r-R)+iq(r-R)},$$

approximately. If we assume

$$n(\mu-1)+qR=D\cos\epsilon \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (98),$$

$$qR=D\sin\epsilon \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (99),$$

this may be written

$$-\frac{2n+1}{2\pi}\cdot\frac{q^2\mu}{D}\cdot\left(\frac{R}{r}\right)^{2n+1}\cdot e^{q(r-R)+i\left\{q(r-R)+\frac{\pi}{4}-\epsilon\right\}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (100).$$

From this result we draw conclusions similar to those of § 5. The depth ν within which the maximum intensity of current falls to $1/e$ of its surface values is

$$\nu=2\pi/q=\sqrt{\frac{\rho}{\mu p}}.$$

In the case of iron we have, using the same data as before, $\nu=\cdot078$ centim. for a frequency of 4000, or $\nu=\cdot78$ for a frequency of 40. The value of ν is thus, for the same frequency, very much smaller than in copper. But the integral currents induced, under the same circumstances, are much more intense in an iron sphere than in a copper sphere of the same size. Integrating (100) with respect to r through the thickness of the stratum in which the currents are sensible, we find for the components of flow at any point of the equivalent *current sheet*

$$\left.\begin{aligned} u'&=\mathrm{K}\left(y\frac{d}{dz}-z\frac{d}{dy}\right)\mathrm{X}_n \\ v'&=\mathrm{K}\left(z\frac{d}{dx}-x\frac{d}{dz}\right)\mathrm{X}_n \\ w'&=\mathrm{K}\left(x\frac{d}{dy}-y\frac{d}{dx}\right)\mathrm{X}_n \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (101),$$

where

$$\mathrm{K}=-\frac{2n+1}{2\sqrt{2\pi\mathrm{R}}}.\frac{q\mathrm{R}}{\mathrm{D}}.\mu.e^{i\left(\frac{\pi}{4}-\epsilon\right)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (102).$$

The disturbance in the field, due to the presence of the sphere, is given by

$$a_1=n\frac{d\mathrm{X}_{-n-1}}{dx},\ b_1=\&c.,\ c_1=\&c. \quad . \quad . \quad . \quad . \quad . \quad . \qquad (103),$$

where

$$\mathrm{X}_{-n-1}=\left[\frac{2n+1.\mu}{\mathrm{D}}e^{-i\epsilon}-1\right]\frac{\mathrm{R}^{2n+1}}{r^{2n+1}}\mathrm{X}_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (104).$$

The order of magnitude of the first term within [ ] depends on the relative magnitudes of qR and μ. So long as qR, though itself large, is moderately small in comparison with $n\mu$ the effect is mainly due to the induced magnetization of the sphere, and is much the same as if the substance were destitute of electrical conductivity, although the distribution of the magnetization within the sphere is very different. On the other hand when qR is large compared with $n\mu$ the first term in [ ] is less important, and the results approximate more to the form which they would assume in the case of infinite conductivity. The following table gives the values of D and ϵ for iron, in the case $n=1$, corresponding to various values of qR.

qR.	10.	50.	100.	1000.
D ϵ	412 1°.23′	455 6°.19′	512 11°.16′	1722 35°.30′

The relation between q and the frequency p is for iron

$$q=1{\cdot}27\sqrt{p}.$$

4 A 2

11. In the whole of the preceding investigations it has been assumed that the quantity j of § 2 may without sensible error be put $=0$. I proceed to sketch the method to be pursued when we do not make this assumption, confining myself for simplicity to the case of $\mu=1$ everywhere. The fundamental equations to be satisfied are :—for the spherical conductor (18) and (19); for the surrounding dielectric (21) and (22).

In the solution of the *First Type* the values of F, G, H and of a, b, c inside the sphere are then given by (27) and (34), respectively. Outside the sphere we shall now have

$$\mathrm{F}=\psi_n(jr)\left(y\frac{d}{dz}-z\frac{d}{dy}\right)\mathrm{X}_n+\psi_{-n-1}(jr)\left(y\frac{d}{dz}-z\frac{d}{dy}\right)\mathrm{X}_{-n-1} \quad . \quad . \quad . \quad (105),$$

where X_n, X_{-n-1} are solid harmonics of the degrees indicated. The values of G and H may be written down from symmetry. We thence find

$$a=-\left\{(n+1)\psi_{n-1}(jr)\frac{d\mathrm{X}_n}{dx}-n\frac{j^2r^{2n+3}}{2n+1.2n+3}\psi_{n+1}(jr)\frac{d}{dx}\mathrm{X}_nr^{-2n-1}\right\}+\text{terms in }\mathrm{X}_{-n-1} \,. \quad (106),$$

with symmetrical formulæ for b, c. The "terms in X_{-n-1}" are to be derived from the preceding line by writing $-n-1$ for n throughout.

The continuity of F, G, H at the surface of the sphere requires

$$\psi_n(k\mathrm{R})\chi_n=\psi_n(j\mathrm{R})\mathrm{X}_n+\psi_{-n-1}(j\mathrm{R})\mathrm{X}_{-n-1} \quad . \quad . \quad . \quad . \quad . \quad (107),$$

when $r=\mathrm{R}$. The continuity of a, b, c requires in addition

$$\psi_{n-1}(k\mathrm{R})\chi_n=\psi_{n-1}(j\mathrm{R})\mathrm{X}_n+\frac{j^2\mathrm{R}^2}{2n-1.2n+1}\psi_{-n}(j\mathrm{R})\mathrm{X}_{-n-1} \quad . \quad . \quad . \quad (108).$$

In the solutions of the *Second Type* the forms of F, G, H, a, b, c inside the sphere are given as before by (40) and (43); whilst in the dielectric we shall now have

$$\phi=\Phi_n+\Phi_{-n-1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (109),$$

and

$$\mathrm{F}=-\frac{1}{\lambda}\frac{d\Phi_n}{dx}-\frac{1}{\lambda}\frac{d\Phi_{-n-1}}{dx}+n+1.\psi_{n-1}(jr)\frac{d\Omega_n}{dx}-n\frac{j^2r^{2n+3}}{2n+1.2n+3}\psi_{n+1}(jr)\frac{d}{dx}\Omega_nr^{-2n-1}$$
$$+\text{terms in }\Omega_{-n-1} \quad . \quad (110),$$

with symmetrical formulæ for G, H. The symbols Φ_n, Φ_{-n-1}, Ω_n, Ω_{-n-1} stand for solid harmonics of the algebraical degrees indicated by the suffixes. The foregoing expressions make

$$a=-j^2\psi_n(jr)\left(y\frac{d}{dz}-z\frac{d}{dy}\right)\Omega_n+\text{ terms in }\Omega_{-n-1}\quad . \quad . \quad . \quad . \quad (111),$$

with symmetrical formulæ for *b* and *c*.

The continuity of ϕ at the surface requires

$$\phi_n=\Phi_n+\Phi_{-n-1}\quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (112),$$

when $r=R$. The continuity of F, G, H requires

$$-\frac{\phi_n}{\lambda}+(n+1)\psi_{n-1}(kR)\omega_n$$
$$=-\frac{\Phi_n}{\lambda}+(n+1)\psi_{n-1}(jR)\Omega_n+(n+1)\frac{j^2R^2}{2n-1.2n+1}\psi_{-n}(jR)\Omega_{-n-1}\quad . \quad . \quad (113),$$

and

$$-n\frac{k^2R^2}{2n+1.2n+3}\psi_{n+1}(kR)\omega_n=-\frac{\Phi_{-n-1}}{\lambda}-n\frac{j^2R^2}{2n+1.2n+3}\psi_{n+1}(jR)\Omega_n-n\psi_{-n-2}(jR)\Omega_{-n-1}\,.\,(114).$$

Adding (113) and (114), and taking account of (112), we find

$$\{kR\psi'_n(kR)+(n+1)\psi_n(kR)\}\omega_n$$
$$=\{jR\psi'_n(jR)+(n+1)\psi_n(jR)\}\Omega_n+\{jR\psi'_{-n-1}(jR)-n\psi_{-n-1}(jR)\}\Omega_{-n-1}\quad (115),^*$$

where some reductions have been effected by means of (29) and (30).

The continuity of *a*, *b*, *c* requires

$$k^2R^2\psi_n(kR)\omega_n=j^2R^2\psi_n(jR)\Omega_n+j^2R^2\psi_{-n-1}(jR)\Omega_{-n-1}\,.\quad . \quad . \quad . \quad (116).$$

12. Let us now apply the foregoing results to the case of *free* motion. A certain relation must then hold between the surface values of X_n and X_{-n-1}, and also between those of Ω_n and Ω_{-n-1}, viz.: a relation expressing that the disturbance at infinity in the dielectric is finite. It may be shown that F, G, H are determinate when the values of $xF+yG+zH$ and of $xa+yb+zc$ are known at every point of space. Now in the first type we have $xF+yG+zH=0$, and

$$xa+yb+zc=-n.n+1.\{\psi_n(jr)X_n+\psi_{-n-1}(jr)X_{-n-1}\}\quad . \quad . \quad . \quad (117).$$

For large values of *r* we have

$$\psi_n(jr)=(-)^n.3.5\ldots 2n+1.\frac{\sin\left(jr+n\frac{\pi}{2}\right)}{(jr)^{n+1}}\quad . \quad . \quad . \quad . \quad . \quad (118).$$

---

[*] Equations (109) and (115) express that the tangential components of current just outside and just inside the sphere are in the ratio of j^2 to k^2. This may also be easily deduced from the fundamental equations (18) and (21).

The last line of (28) is not a convenient expression when n is negative. But we readily deduce from (30)

$$\zeta^{-2n-1}\psi_{-n-1}(\zeta)=-\frac{1}{2n-1}\frac{d}{\zeta d\zeta}[\zeta^{-(2n-1)}\psi_{-n}(\zeta)] \quad . \quad . \quad . \quad . \quad . \quad (119);$$

and by successive applications of this formula of reduction we find

$$\psi_{-n-1}(\zeta)=\frac{(-)^n\zeta^{2n+1}}{1.3\ldots 2n-1}\cdot\left(\frac{d}{\zeta d\zeta}\right)^n\frac{\cos\zeta}{\zeta} \quad . \quad . \quad . \quad . \quad . \quad . \quad (120);$$

since, by (28), $\psi_{-1}(\zeta)=\cos\zeta$. This result, like (28), has been given in somewhat different forms by various writers.* When r is large it gives

$$\psi_{-n-1}(jr)=\frac{(-)^n(jr)^n}{1.3\ldots 2n-1}\cos\left(jr+n\frac{\pi}{2}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (121).$$

In free motion λ is real and negative. We may therefore write $j=-i\lambda/v=i\gamma$ where γ is real, and may be taken positive. Substituting in (118) and (121), and expressing that the terms in $e^{\gamma r}$ must disappear from (117), we are led to the following relation between the surface values of X_n and X_{-n-1}

$$3.5\ldots 2n+1.X_n-i\frac{(jR)^{2n+1}}{1.3\ldots 2n-1}X_{-n-1}=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (122).$$

Similarly in the free motions of the second type we must have

$$3.5\ldots 2n+1.\Omega_n-i\frac{(jR)^{2n+1}}{1.3\ldots 2n-1}\Omega_{-n-1}=0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (123).$$

The equation to determine the various values of λ is to be obtained, in the first type by elimination of χ_n, X_n, X_{-n-1} between (107), 108), and (122), and in the second type by elimination of ω_n, Ω_n, Ω_{-n-1} between (115), (116), and (123).

In all practical cases jR is exceedingly small. If we neglect all powers of jR above the second we have

$$X_n=0, \quad \Omega_n=0.$$

In the first type we then obtain

$$\psi_{n-1}(kR)=\frac{j^2R^2}{2n-1.2n+1}\psi_n(kR) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (124),$$

approximately. For a first approximation $kR=\vartheta$, where ϑ is a root of $\psi_{n-1}(\vartheta)=0$; and for a second

$$kR=\vartheta\left(1-\frac{1}{2n-1}\frac{j^2}{k^2}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (125).$$

---

* See C. NIVEN, Phil. Trans., 1880, p. 126. Also HEINE, 'Kugelfunctionen,' t. i., § 60.

Now $j^2/k^2=\lambda\rho/4\pi v^2$, and $\lambda=-k^2\rho/4\pi=-\rho\vartheta^2/4\pi\mathrm{R}^2$, approximately. Hence (125) becomes

$$k\mathrm{R}=\vartheta\left\{1+\frac{\rho^2\vartheta^2}{16(2n-1)\pi^2v^2\mathrm{R}^2}\right\}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (126)$$

In the second type we have

$$\frac{k^2\mathrm{R}^2\psi_n(k\mathrm{R})}{k\mathrm{R}\psi'_n(k\mathrm{R})+(n+1)\psi_n(k\mathrm{R})}=-\frac{j^2\mathrm{R}^2}{n},$$

or

$$\psi_n(k\mathrm{R})=-\frac{j^2}{nk^2}k\mathrm{R}\psi'_n(k\mathrm{R}) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (127),$$

to the same degree of accuracy. For a first approximation $k\mathrm{R}=\vartheta$, a root of $\psi_n(\vartheta)=0$, and for a second

$$\begin{aligned} k\mathrm{R}&=\vartheta\left(1-\frac{j^2}{nk^2}\right) \\ &=\vartheta\left(1+\frac{\rho^2\vartheta^2}{16n\pi^2v^2\mathrm{R}^2}\right). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (128). \end{aligned}$$

By combining together in the proper way solutions of this type we should be able to represent analytically the decay of any given non-uniform electrification of the surface of the sphere. The formula (128) would indicate that in any particular mode the lines of flow of electricity in the sphere are for the most part closed curves, all those which abut on the surface being confined to a stratum of thickness $\rho^2\vartheta^2/16n\pi^2v^2\mathrm{R}$. For $n=1$, and $\vartheta/\pi=1{\cdot}4303$, this $=1{\cdot}42\times10^{-23}\times\rho^2\mathrm{R}^{-1}$. In the case of any ordinary metallic conductor this would be much smaller than the dimensions of a molecule.* A result of this character cannot of course be interpreted literally. All that we can safely assert is that the currents by which the redistribution of the superficial electrification is effected are confined to a very thin film, and are probably subject to laws not yet investigated.

In the case of a globe of water [$\rho=7{\cdot}18\times10^{10}$ at 22° C.] the result is more intelligible; viz., the thickness of the stratum in question is then $=\cdot73\mathrm{R}^{-1}$.

13. The case of periodic induced currents [$\lambda=2\pi ip$ where p is prescribed] may be treated as follows. Let P, Q, R denote the components of electromotive force, viz.:

$$\mathrm{P}=-\frac{d\phi}{dx}-\lambda\mathrm{F},\ \mathrm{Q}=\&\mathrm{c.},\ \mathrm{R}=\&\mathrm{c.}$$

It is easily seen that if the suffix $_0$ be used to distinguish the parts of a, b, c, P, Q, R due to the inducing system, the functions $xa_0+yb_0+zc_0$ and $x\mathrm{P}_0+y\mathrm{Q}_0+z\mathrm{R}_0$ must admit of expansion (in the neighbourhood of the origin) in the forms

---

* There is nothing peculiar to MAXWELL's theory in the order of magnitude of this result.

$$xa_0+yb_0+zc_0=\Sigma\psi_n(jr)\Theta_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (129),$$

$$xP_0+yQ_0+zR_0=\Sigma\psi_n(jr)Z_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (130),$$

where Θ_n, Z_n are solid harmonics of positive degree n. Now $xa+yb+zc$ and $xP+yQ+zR$ must differ from the above by terms representing a disturbance propagated wholly outwards. But

$$xa+yb+zc=-n.\overline{n+1}.\{\psi_n(jr)X_n+\psi_{-n-1}(jr)X_{-n-1}\},$$
$$xP+yQ+zR=-\lambda n.\overline{n+1}.\{\psi_n(jr)\Omega_n+\psi_{-n-1}(jr)\Omega_{-n-1}\}.$$

The condition that

$$\psi_n(jr)\left(X_n+\frac{1}{n.\overline{n+1}}\Theta_n\right)+\psi_{-n-1}(jr)X_{-n-1}$$

should represent a disturbance travelling outwards may be shown to be

$$3.5\ldots\overline{2n+1}\left(X_n+\frac{1}{n.\overline{n+1}}\Theta_n\right)+i\frac{(jR)^{2n+1}}{1.3\ldots\overline{2n-1}}X_{-n-1}=0 \quad . \quad . \quad . \quad (131),$$

where in the harmonics X_n, &c., r is supposed put $=R$. Similarly we have, on the same understanding,

$$3.5\ldots\overline{2n+1}\left(\Omega_n+\frac{1}{n.\overline{n+1}}\frac{Z_n}{\lambda}\right)+i\frac{(jR)^{2n+1}}{1.3\ldots\overline{2n-1}}\Omega_{-n-1}=0 \quad . \quad . \quad . \quad (132).$$

The equations (107), (108), and (131) determine χ_n, X_n, X_{-n-1} in terms of Θ_n; whilst (115), (116), and (132) determine ω_n, Ω_n, Ω_{-n-1} in terms of Z_n. Thus the complete solution of our problem is effected.

Introducing the consideration that jR is small, we find, in the solutions of the second type,

$$\Omega_n=-\frac{1}{n.\overline{n+1}}\frac{Z_n}{\lambda},$$

approximately, and thence

$$k^2\psi_n(kr)\omega_n=-\frac{2n+1}{n^2.\overline{n+1}}\frac{j^2}{\lambda}Z_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (133),$$

by (115) and (116). If σ_n denote the n^{th} harmonic constituent of the surface distribution of electricity, we deduce

$$\sigma_n=\frac{1}{\lambda}\frac{d\sigma_n}{dt}=\frac{1}{4\pi v^2R}.\frac{2n+1}{n}.Z_n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (134).$$

For the first harmonic constituent we have the simple formula

$$\sigma_1=\frac{3(xf'+yg'+zh')}{\mathrm{R}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (135),$$

if f', g', h' denote the components of the electric displacement which would obtain at the origin if the spherical conductor were removed.

The equation (134) expresses that so long as $p\rho$ is small compared with v^2 the surface-density of electricity at any point will have at each instant the statical value corresponding to the distribution of electromotive force at that instant due to the external system. The arrangement of the currents in the sphere by which the changes in the superficial distribution are effected will however depend materially on the relation between the period of the changes in the field and the time of decay of free currents in the sphere. The discussion of this point can be conducted as in the case of the solutions of the first type, treated in § 5, and the results are analogous to those there found. When the spherical harmonics involved are zonal, the work and the interpretation are much facilitated by the use of the current-function Ψ, whose value is given by (56).

XIV. *Researches on the Foraminifera—Supplemental Memoir.*

On an Abyssal type of the Genus Orbitolites ;—*a Study in the Theory of Descent.*

By William B. Carpenter, *C.B., M.D., LL.D., F.R.S.*

Received May 31,—Read June 14, 1883.

[Plates 37, 38.]

Introduction.

The subject of this communication is a type of the genus *Orbitolites*—first obtained in the deep-sea dredgings of H.M. Surveying Ship "Porcupine," off the north-west of Ireland, in 1869,* and subsequently brought up from various depths in other parts of the North Atlantic and also in the Mediterranean,—which presents many points of general scientific interest ; the first of these being the completeness of the transition which it establishes between the *Milioline* and the *Orbitoline* plans of growth, and the full confirmation it thus affords of the validity of the principles on which my Classification of the Foraminifera is founded.

In the Monograph of the genus *Orbitolites* (1855), which constituted the First Series of my "Researches on the Foraminifera,"† I embodied the results of a careful and thorough investigation of the structure and relations of all the forms under which that type was then known to me : and I showed that while the most highly developed and most specialized of these forms exhibit the *cyclical* plan of growth almost from the very commencement,—a complete zone of sub-segments being formed by gemmation from the entire periphery of the "circumambient segment" of the central "nuclear mass,"‡ and the whole disk being made up of a succession of similar concentric zones,—there are other forms in which the primary gemmation takes place from only one side of that mass, so as to impart to the early extension of the composite structure a more or less *spiral* direction,§ which only gives place to the cyclical after repeated gemmations. The transition from the one plan of growth to the other I showed to be made by the progressive widening-out of the spire, and the increase in the number of the

---

* *See* Proc. Roy. Soc., vol. 18, p. 397.

† Phil. Trans., 1856, pp. 181–236.

‡ Ibid., Plate IV., figs. 5 and 6.

§ Ibid., Plate IX., figs. 1 to 4.

sub-segments (formed by the division of the principal segments) at every new stage of gemmation; so that at last the *alæ* of the spire, extending themselves on either side round the nuclear mass, meet and complete the circlet, around which new zones are then successively budded forth, as in the forms that are cyclical from their commencement.

I did not at that time feel justified in calling in question the validity of the order *Cyclostègues*, which had been instituted by M. D'ORBIGNY, for the reception of this and other types characterised by the cyclical plan of growth; but in my Second Series (presented in the following year), which contained the results of a similar investigation of the genus *Orbiculina*, I showed that the latter *always* begins life on the spiral plan of growth, which may or may not give place subsequently to the cyclical, and that the marginal portions of a full-grown cyclical *Orbiculina* cannot be distinguished from similar portions of an *Orbitolite*. From this fact I drew the conclusion* that although *Orbitolites* and *Orbiculina* had been placed by M. D'ORBIGNY in two distinct orders, *Cyclostègues*, and *Helicostègues*, "the relationship between them must be extremely close;" and ventured further to affirm that no Classification can have any claim to be considered as *natural*, in which they shall be widely separated."

To this point I reverted in the Concluding Summary appended to my Fourth Memoir,† in which I showed how completely the results of my researches were opposed to the principles on which the Classification of M. D'ORBIGNY had been framed, indicated the line of "descent with modification" by which a division of the primary segments that form the simply-chambered shell of a *Peneroplis* into sub-segments would give origin to the chamberlets of the spiral *Orbiculina*, and pointed out how gradational the transition is from the latter to the cyclical *Orbitolites*.

When I subsequently undertook, in conjunction with my friends, W. K. PARKER and T. RUPERT JONES, to frame an entirely new Classification of FORAMINIFERA on the basis of the principles I had laid down, I felt no difficulty in assenting to their view that the pedigree of this series might be traced yet further back, viz.: to those simplest forms of the *Milioline* type, whose shell is a flattened nautiloid spire altogether destitute of partitions—thus belonging to that *monothalamous* section which all previous Systematists had ranked as fundamentally distinct from the *polythalamous*. "From the undivided spiral of *Cornuspira*," I pointed out ("Introduction to the Study of the Foraminifera," p. 67), "to the regular scarcely-divided spiral of certain 'spiroloculine' forms of *Miliola*, the transition is almost insensible; and from the 'spiroloculine' we pass by easy steps to all the other forms of the *Milioline* type." Again, a subdivision of the widely-expanded spire of *Cornuspira* into segmental chambers gives us *Peneroplis*, with its septal planes perforated by a row of separate pores; while from this, it was again pointed out, the spiral *Orbiculina* might

---

* Phil. Trans., 1856, p. 552.

† Ibid., 1860, p. 571.

be derived by a further division of the segments of the sarcodic body into subsegments, with a corresponding division of the primary chambers of the shell into chamberlets.

In the new specific type of *Orbitolites* I have now to describe, the whole transition which I thus hypothetically indicated, is actually presented during the successive stages of its growth. For it begins life as a *Cornuspira*, taking-on that 'spiroloculine' condition which marks the passage towards the *Milioline* type: its shell forming a continuous spiral tube, with slight interruptions at the points at which its successive extensions commence; while its sarcodic body consists of a continuous coil, with slight constrictions at intervals. The *second* stage consists in the opening-out of its spire, and in the division of its cavity at regular intervals by transverse septa, traversed by separate pores, exactly as in *Peneroplis*. The *third* stage is marked by the subdivision of the 'peneropline' chambers into chamberlets, as in the early forms of *Orbiculina*. And the *fourth* consists in the exchange of the spiral for the cyclical plan of growth, which is characteristic of *Orbitolites;* a circular disk of progressively increasing diameter being formed by the addition of successive annular zones around the entire periphery. This increase in diameter is not here accompanied (as it is in most of the other forms of the *Orbitoline* type) by a corresponding augmentation in thickness; and as the extraordinary tenuity of these disks affords an easily recognisable and (as I believe) a constant differential character of the species, I proposed in 1870[*] to designate it *Orbitolites tenuissima.*

ORBITOLITES TENUISSIMA. *Carpenter*, 1870.

The disks of *O. tenuissima* are usually almost perfectly flat (Plate 37, fig. 1), and exhibit a remarkable regularity of structure. The diameter of the largest complete specimen I have seen is not above 0·25 inch; but it is obvious from the size and curvature of the fragments which the dredges frequently contained, that they must have belonged to disks whose diameter was at least 0·6 inch, these larger specimens having come to pieces in their rough removal from the soft and tranquil ooze on which they had previously lain. This fragility depends in part upon the extreme tenuity of the disks, their thickness rarely exceeding *one three-hundredth* of an inch; and in part on the slightness of the connexion which (as I shall presently show) exists between the successive zones.[†]

When either surface of the disk of *O. tenuissima* is viewed by reflected light under a low magnifying power, its concentric zones are seen to be crossed by radial lines (Plate 37, figs. 1, 2) resembling those which pass between the septal bands of *Peneroplis*. But when a portion of the disk is viewed under a higher power by transmitted light,—which, through the extreme tenuity of its superficial lamellæ, brings its internal structure into distinct view (Plate 38, fig. 5),—these lines are seen not to be mere surface-markings, as in *Peneroplis*, but to be the indications of internal shelly partitions, which divide each flattened annular chamber into a series of narrow chamberlets, resembling those which I formerly described as constituting the two superficial layers of the "complex" type of *Orbitolites*.* Here, however, these chamberlets form but a single plane, as in the "simple" type formerly described; and the pores by which the last-formed annulus opens at the margin of the disk are arranged in single series (Plate 37, figs. 4, 5). It is worthy of note that these pores are not round, like those of ordinary *Orbitolites*, whether of the "simple" or of the "complex" type;† but are more or less elongated in the plane of the disk—a peculiarity obviously related to its extreme compression. Similar pores are seen upon the edge of any zone from which the zone external to it has been detached by fracture; and it is obvious that they constitute the channels of communication between the cavitary system of each zone and that of the zones internal and external to it; while the marginal series brings the cavitary system of the peripheral zone (and, through it, that of every interior zone backwards to the spiroloculine "nucleus") into relation with the surrounding medium.

---

[*] Proc. Roy. Soc., vol. 19, p. 176.

[†] In *Cycloclypeus*, the marginal portions of the disk, though of even greater tenuity, have not by any means the same fragility; partly because its *vitreous* shell-substance is much firmer than the *porcellanous* shell-substance of *Orbitolites*, and partly because a layer of it is usually continued from each new zone over the whole surface of the previously formed disk. See Phil. Trans., 1856, p. 558.

When a portion of the thin shelly lamella forming either surface of the disk has been removed by dilute acid, so as to lay open the cavity beneath (Plate 37, fig. 2), it is seen that each zone of chamberlets lies between two concentric rings of shell, *a*, *a*, *b*, *b*; and that the radiating partitions, *c*, while springing from the inner shell-ring, do not extend to the outer, so that a continuous gallery is there left, into which all the chamberlets open at their peripheral extremities. And when we examine the disk by transmitted light (Plate 38, fig. 5), we see it to be from this gallery—not from the chamberlets—that the pores of the shell-ring which incloses it proceed.

Whilst the structure of the concentric zones forming the peripheral portion of the disk thus corresponds in all its essential characters with that of the ordinary "simple" type described in my former Memoir, the structure of the central portion of the disk is altogether different. The spheroidal "primordial chamber" (Plate 38, fig. 3, *a*) is extremely minute, not exceeding 1-1000th inch in diameter, and from this proceeds a compressed shelly tube, which forms a nautiloid spiral around it (Plate 38, figs. 3, 5) each successive turn slightly increasing in breadth, so as closely to resemble the first-formed part of the spire of *Cornuspira*. The continuity of its cavity, however, is interrupted, usually at about every two-thirds of a turn, by a thickening of its wall (Plate 38, fig. 3, *b*), which seems to have been formed as a sort of foreshadowing of a septum at each addition to its length; and thus, as long as the growth of the shell proceeds upon the same plan, it is a 'spiroloculine' *Miliola*.

---

* Phil. Trans., 1856, p. 202, Plate V., fig. 6, *c*, *c*; Plate VII., fig. 12.

† Ibid., Plate V., figs. 1 and 6, *d*, *d*.

But after making from six to eight turns (the number varying in different individuals) the spire begins to open out in the horizontal plane (Plate 38, fig. 5, *a*) without any vertical enlargement, and a complete septum is formed at the next break, marking off the first principal chamber from the previously-formed spiral tube. This septum is traversed, as in *Peneroplis*, by a variable number (*four* in the specimen here figured) of passages, which would show themselves as pores upon its external surface; but these, instead of opening into another single undivided chamber, lead into as many chamberlets, which are formed by the subdivision of the next principal chamber, *b*, by radial partitions, exactly as in *Orbiculina*. This chamber, in the individual here figured, is not separated by a completely-formed septum from the succeeding chamber, *c*, and the latter is undivided save by a single radial partition; but this is a mere individual variation,—which is of interest, however, as showing that the subdivision of the chambers into chamberlets is a secondary, not a primitive formation. The septum which closes-in the chamber *c* is traversed by 13 pores, which open into as many chamberlets formed by the subdivision of the next principal chamber; the separation of these chamberlets by radial partitions being complete for about four-fifths of the length of the chamber (that is, of the distance between its inner and its outer septum), but deficient for the outer fifth, so as to leave the continuous gallery *d*, *d*, into which all the chamberlets open at their outer ends. This chamber, it will be observed, extends itself on either side at *d′*, *d′*, so as to enclose a portion of the spiroloculine "nucleus;" and this extension is still more marked in the next chamber, whose two alæ, *e′*, *e′*, reach the ends of the transverse diameter of the original spire. The septum which separates this chamber from the preceding has the number of its pores increased to 30; and these open outwards into as many chamberlets in the next-formed chamber. As new chambers are successively added, the backward extension of their alæ is carried further and further, until (in the individual here figured, Plate 37, fig. 1) those of the ninth chamber meet at the back of the spiroloculine "nucleus," so as to enclose it all round, and the tenth chamber forms a complete ring of chamberlets, whose derivation from the undivided chamber of the 'peneropline' type is made obvious by the previous transition. With each increase in the length of the septal plane, there is a proportionate increase in the number of pores by which it is traversed, the distance between them having a very uniform average; and the number of these pores determines the number of chamberlets in the next annulus, which has thus no definite relation to that of the chamberlets in either of the last-formed or in the subsequently-formed annulus. The breadth of the zones (and, consequently, the length of their chamberlets) has a range of variation from 1-180th to 1-80th of an inch, its general average being 1-120th inch; so that a disk having a diameter of 0·6 inch (or a radius of 0·3) would be made up of about forty such concentric zones. A very narrow zone is occasionally seen to intervene between two zones of ordinary breadth; but, as I have always found this to originate in a fractured portion of the preceding zone which then formed the margin of the disk, it would seem to have been a special reparative addition.

The whole cavitary system, from the primordial chamber to the marginal annular gallery, is occupied by a continuous sarcodic body of a dark olive-green hue (Plate 38, fig. 1). Although this body may be said to consist at any one moment of a multitude of sub-segments, connected together by annular and radiating stolon-processes, yet, from what we know of its semi-fluid condition in the living animal, we may pretty confidently surmise that this subdivision is by no means permanent, but that an interchange is continually taking place between the protoplasmic contents of the inner and the outer portions of the cavitary system, so that what occupies the central spire at any moment may be transferred in no long time to the marginal annulus, and *vice versâ*.

The extreme tenuity of this sarcodic body, and the transparence of the shelly laminæ that invest it, have enabled me very distinctly to recognise, by light transmitted through the disk, the presence of nucleus-like bodies (Plate 38, fig. 2) of about 1-1750th of an inch in diameter, imbedded in its substance. As might be expected from the consideration just stated, these corpuscles are very irregularly distributed. In the specimen here figured (Plate 38, fig. 1), two of the outer half-whorls of the 'spiroloculine' centre (shown on a larger scale at *b*, *b*, *b*′, *b*′, fig. 4), are crowded with them; while in a single chamberlet, *c*, of one of the interior annuli, there are as many as five. Elsewhere, on the other hand, they present themselves with less frequency, only one or two occurring in any single chamberlet (*d*, *d*, *d*), and a large proportion of the chamberlets being entirely destitute of them. The finding of these corpuscles in the highly composite sarcode-body of *Orbitolites* is an interesting extension of the discovery, of Dr. R. HERTWIG, of corpuscles regarded by him as nuclei, in what I long since characterised as the "reticularian" type of RHIZOPODA, of which the ordinary FORAMINIFERA are the testaceous forms. This discovery was first made in the fresh-water Monothalamous *Mikrogromia*,* and subsequently extended by him to various marine Polythalamia, such as *Spiroloculina*, *Globigerina*, and *Rotalia*,† and by F. E. SCHULTZE to *Quinqueloculina*, *Lagena*, *Polystomella*, and *Planorbulina*.‡ What is the function of these corpuscles in that indefinite extension of the protoplasmic body, and the multiplication of its segments, which is so remarkable a character of this type, is not yet apparent; but that they do *not* become the centres of distinct cells separated from each other by any limiting membrane, or even of permanent segments or sub-segments, may be regarded as certain. If the nuclear character of these corpuscles be admitted, the entire composite organism thus seems to present a most interesting link of connexion between the *unicellular* and *multicellular* types; the absolute continuity of its protoplasmic substance entitling it to rank with the former, whilst in the multiplication of its nuclei it obviously tends towards the latter.

---

* Archiv für Mikrosk. Anat., Bd. x., Supplementheft (1874) p. 1.

† Jenaische Zeitschrift, Bd. x., 1876, p. 41, &c.

‡ Archiv für Mikrosk. Anat., Bd. xiii., 1877, p. 9.

The growth of this beautiful organism doubtless takes place after the completion of the first annulus, in the manner described in my former Memoir (§ 35). The sarcodic body, when enlarged by the nutriment it has appropriated, will project itself through the marginal pores, in quantity sufficient to form, by the coalescence of its separate protrusions, a continuous belt of sarcode; and in the substance of this a set of radial calcareous partitions will be deposited, commencing between the pores of the margin of the previous shell-ring, while two horizontal lamellæ are formed on the superficial planes, to constitute, as it were, the floor and ceiling of the new circle of chamberlets. These horizontal lamellæ overlap but very slightly the margin of the previous annulus (Plate 37, fig. 3, *a*, *a*); and their adhesion to it is generally so weak that the annuli readily come apart. As the subdivision of the annulus into chamberlets does not extend to its outer portion, a passage is left (seen in vertical section at *b*, *b*, *b*, fig. 3), which is occupied by a continuous ring of sarcode, as shown in Plate 38, fig. 1; and from this ring proceed the stolons which pass outwards through the pores of the septum that closes it in.

The homogeneousness of the protoplasmic substance by which the entire cavitary system is occupied, is shown (as in the types formerly described) by the completeness with which the effects of injuries are repaired, and the plan of the original fabric restored (see Phil. Trans., 1856, Plate VIII., figs. 4–9). Not only is the loss of any part of the disk repaired by the formation of a new and continuous annulus along the broken as well as the unbroken margin, so that the next and all succeeding zones follow the new contour (as shown in Plate 37, fig. 6); but a new and entire annulus of chamberlets may form itself around the whole circumference of a mere marginal fragment (fig. 7), by the enclosure of which in a subsequent succession of annuli, the discoidal form characteristic of the type is completely and characteristically restored. Owing to the transparence of these attenuated disks, I have been able to assure myself that *every part* of the margin of this fragment, whether broken or unbroken, peripheral, central, or lateral, has contributed to the formation of the first new complete annulus, by which the foundation was laid of the subsequent regular series of concentric zones; thus clearly indicating that a sarcodic extension took place from every chamberlet laid open by the fracture, as well as from the normal pores of the last-formed septal plane, and that these extensions coalesced to form a continuous ring, as in the formation of the ordinary succession of concentric annuli.

This perfect reproduction of a form of peculiar regularity, in a type of animal organisation so low that its body-substance does not show any advance upon the primitive protoplasmic condition, is, in itself, a matter of great interest. But the interest is much enhanced by the consideration that this organism begins life, and forms its first shelly envelope, upon a plan altogether different; exchanging this for its later mode of growth, by a transition so rapid as to manifest the almost sudden attainment of a much more specialised character. And when this transition has been once made, there appears no disposition whatever, in the reparation of injuries, to a reversion to the earlier plan. Now, this is a "pregnant instance" of the following "law of formation," sagaciously laid down long since by Sir JAMES PAGET:—"When, in an adult animal, a part is reproduced after injury or removal, it is made in conformity, not with that condition which was proper to it when it was first formed, or in its infantile life, but with that which is proper according to the time of life in which it is reproduced; proper, because like that which the same part had, at the same time of life, in members of former generations." And the study of this humble *Orbitolite* will be found, not only in this, but in other particulars, to justify the profound remark made by the same philosophic Pathologist,[*] long before the promulgation of the doctrine of "evolution," that, "if we are ever to escape from the obscurities and uncertainties of our art, it must be through the study of those highest laws of our science which are expressed in the simplest terms in the lives of the lowest orders of creation."

Geographical, Bathymetrical, and Geological distribution.

So far as is at present known, *Orbitolites tenuissima* inhabits only the North Atlantic Ocean and the seas in communication with it. The first complete specimens were obtained in the "Porcupine" dredgings of 1869, at depths of from 630 to 1,443 fathoms, between the north-west of Ireland and Rockall Bank. In the "Porcupine" expedition of 1870, however, it was brought up from a bottom of only 64 fathoms in Setubal Bay, on the coast of Portugal, and afterwards from a shallow bottom within the Mediterranean, near Carthagena. That it is an inhabitant of other parts of the Mediterranean I then inferred from the fact that I had detected fragments of it in the Foraminiferal dredgings, made at 250 fathoms by EDWARD FORBES and Lieut. (now Admiral) SPRATT in the Ægean, in 1842; and it is stated by Dr. J. GWYN JEFFREYS, in his "Report on the Biology of the 'Valorous' Cruise," that it has been dredged by the Marquis DU MONTEROSATO at from 100 to 200 fathoms' depth, off the coast of Sicily. That it might extend far to the north, would be expected from its capability of bearing the low temperature of 37° Fahr., which prevails over the deep bottom from which it was first brought up; and this expectation was verified by its presenting itself in one of the "Valorous" dredgings in Baffin's Bay (lat. 62° 6′ N., depth 1,350 fathoms, temperature 34° 6′ Fahr.), as well as at two stations in the North Atlantic, No. 12, depth 1,450 fathoms, and No. 13, depth 690 fathoms, both in the parallel of 56°. It has been only once brought up, however, in the "Challenger" expedition, viz., at Station 44, off Cape Hatteras, from a bottom of 1,700 fathoms' depth, over which creeps (there is strong reason to believe) an underflow of cold water from the Arctic basin. Several specimens have (I am informed) been since found in a dredging taken by the French exploring-ship "Travailleur" in the Bay of Biscay (Fosse de Cap Breton), at a depth of 1,200 fathoms.

---

[*] "Lectures on Surgical Pathology," 1849;—Lect. VII. General Considerations on Repair and Reproduction.

It would seem, therefore, that *Orbitolites tenuissima* has its proper home on the sea-bottom of the deeper parts of the North Atlantic, where the temperature ranges from 37° to 35° Fahr.; but that it also is capable of living, not only in much shallower, but also in much warmer, waters. For the temperature of the Mediterranean and Ægean, even at depths below 100 fathoms, is never less than 54°, while on the shallow bottom of Setubal Bay, and on the shore-slope near Carthagena, the summer temperature must be considerably higher.

Looking to the singular retention, in this beautiful *Orbitoline*, of the *Milioline* type from which its derivation may now be confidently affirmed, the probability seems strong that it was a very early form; and if identical with COSTA's *Pavonina italica*,* as the imperfect account given by him of that type would seem to indicate, it probably inhabited the Mediterranean during the greater part of the Tertiary period. Its persistence in the abyssal depths of the North Atlantic harmonizes well with the idea of its antiquity; those depths having been found, by the recent exploration of them, to be inhabited by many "survivals" of the Cretaceous and even earlier Faunæ. It may be remarked, finally, that the considerable diameter attained by these very fragile discs, seems a proof of the extreme tranquillity of the deep-sea bottom; since they could not otherwise have gone on growing and extending themselves, without showing more frequent marks of injury and reparation than I have observed in them.

Relation to other Orbitoline Types.

Having been requested by the late Sir C. WYVILLE THOMSON to prepare a Report on the *Orbitolites* collected in the "Challenger" Expedition, I have carefully studied the remarkable gatherings made of them on and near the summit of the Fiji reef, and also at a depth of 18 fathoms on its slope. The result of that examination now enables me to indicate with great probability the successive stages of the evolution of that highly specialised "complex" type, the derivation of which from a Milioline ancestry would have seemed—but for the completeness of the series of intermediate forms—almost inconceivable. And I can now also mark out, with more distinctness than formerly, the types of this Genus, which, in virtue of their constancy and definiteness, are entitled to rank as distinct species.

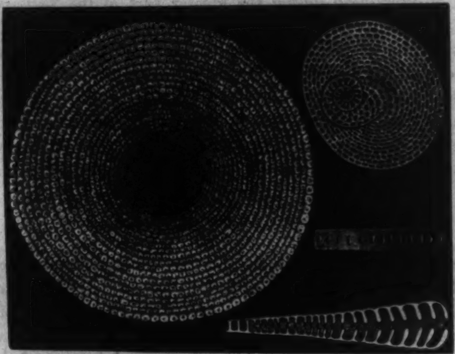
The first of these is the *O. marginalis* of Lamarck, known to him only by small Mediterranean specimens of no more than two millims. (about 0·08 inch) in diameter, but attaining on the Fijian reef a diameter of 0·2 inch, and presenting a much more characteristic aspect than is discernible in the dwarfed Mediterranean form. The well-developed "cycloline" disks of this beautiful form of the "simple" type (fig. I., 1),

---

* See his "Paleontologia del Regno di Napoli," part ii., in 'Atti dell' Accad. Pontan,' vol. vii., p. 178, plate xvi., figs. 26–28.

which I formerly* differentiated only by the singleness of its row of marginal pores (fig. I., 3), I now find to be uniformly characterised by the marked eccentricity of their primordial chamber, and by the spiral direction of their early growth (fig. I., 2), which I formerly supposed to be only occasional variations. In fact, the first formed portion of these disks, like that of a young *Orbiculina adunca* (*loc. cit.*, Plate XXVIII., fig. 2), exactly resembles what a Peneropline shell would be, if its chambers, as they widen out, were to undergo division into chamberlets; thus corresponding in every essential particular with the "orbiculine" stage of *O. tenuissima*. But while we have seen that this stage, in the last-named species, is preceded by a spiroloculine coil, representing a true "milioline" stage, it has no other predecessor in *O. marginalis* than what I formerly designated as the "nucleus," consisting of a flask-shaped "primordial chamber," from the neck of which proceeds a "circumambient chamber" that passes almost completely round it (as in fig. II., 3). The morphological import of this arrangement becomes clearer when we compare the sarcodic bodies of the two types; for it is then obvious that the "circumambient segment," which springs from the "primordial segment," and then, after making a single coil around it, gives off the first "peneropline" segment, really represents the *multiple* spiroloculine coil of *O. tenuissima*; this early generalised "milioline" stage being (as it were) abbreviated with the advance towards specialisation, as we see in numberless cases elsewhere.

Fig. I.—*Orbitolites marginalis*.



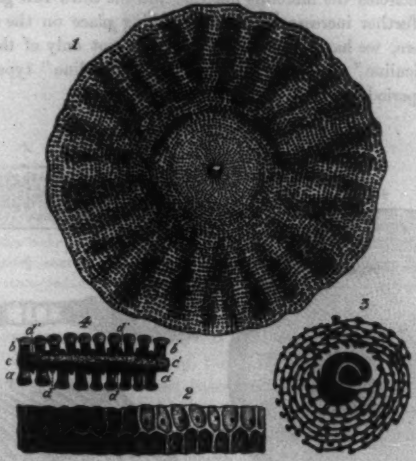
The "Challenger" collection—especially that of the 18 fathoms' dredging—includes a very large number of thin flat disks, attaining a diameter of about 0·32 inch, whose surface often presents rather an "engine-turned" than an annular aspect, and which are specially characterised by the possession of a complete *double* row of marginal

---

* Phil. Trans., 1856, p. 215, Plate VII., fig. 14.

pores (fig. II., 2). Both these peculiarities were noticed in my former Memoir (pp. 215, 221), but were treated as merely varietal modifications. I now find, however, that they accompany one another very constantly; and that the type is so well differentiated by them as to be fully entitled to rank as a distinct species, which I designate *O. duplex.*[*] Notwithstanding the difference in the surface-aspect of its disks, and the doubling of their marginal pores, the sarcodic body of this species conforms in every essential particular to that of the preceding. For each of its concentric annuli consists of a single cord (fig. II., 4, $c\,c'$), that passes through a continuous circular gallery in the median plane of the disk, and carries a double series of columnar sub-segments ($a\,a'$, $b\,b'$), which occupy chamberlets (fig. II., 1) that extend in vertical series to the two surfaces of the disk. But each annular cord, instead of giving off (as in *O. marginalis*) a *single* stolon-process to initiate a sub-segment of the succeeding annulus, gives off *two* such processes between each pair of its own sub-segments (fig. II., 4, $d\,d$, $d'd'$); and these have separate passages through the septal plane—one above and the other below the annular canal, as shown in fig. II., 2,—

Fig. II.—*Orbitolites duplex.*



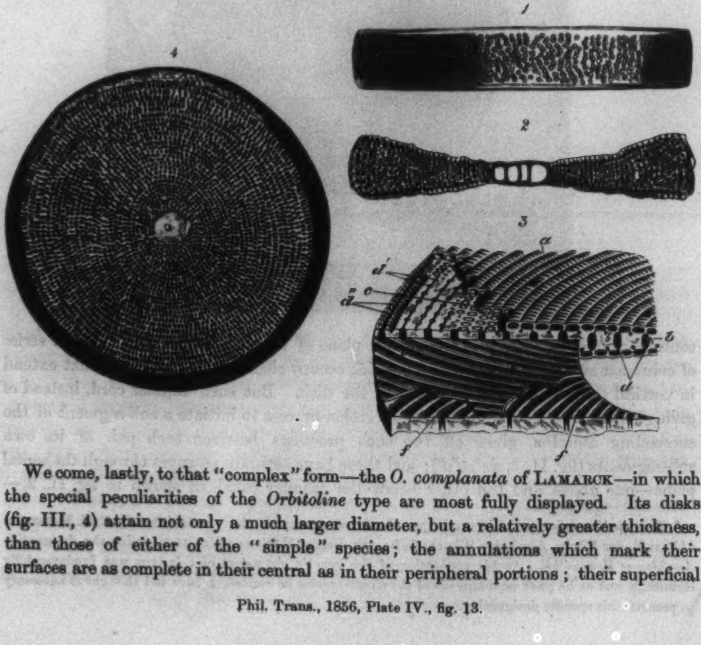
---

[*] This species, as intimated in my former Memoir, appears to be the type described by Prof. EHRENBERG (Abhandl. der König. Akad. der Wissenschaften zu Berlin, 1839) as a BRYOZOON, under the designation *Amphisorus Hemprichii.* As his conception of the generic characters of this type was fundamentally erroneous, and as he gave no diagnosis of the single species he created, I have not thought it necessary to preserve his specific designation.

opening on its external side in a double series. This arrangement, as will presently appear, is the first step in the evolution of the "complex" form of the Orbitoline type.

Another advance upon *O. marginalis* is seen in the more rapid approach of *O. duplex* to the cyclical plan, shown in the abbreviation of the early spiral stage. For the "nucleus" of *O. duplex* has but a slight eccentricity, and its circumambient segment(fig. II., 3, *b*, *b*), instead of putting forth but a single stolon-process, gives off several;* so that, as each of these originates a new sub-segment, a crescentic row of sub-segments is at once constituted. The row formed next in succession to this almost entirely encircles the milioline nucleus, and the third row generally completes the annulus, all further increase in the disk taking place on the cyclical plan. In *O. duplex*, therefore, we have such an abbreviation, not only of the "milioline" but also of the "orbiculine" stage, that the proper "orbitoline" type is attained at a relatively earlier period.

Fig. III.—*Orbitolites complanata.*



We come, lastly, to that "complex" form—the *O. complanata* of **Lamarck**—in which the special peculiarities of the *Orbitoline* type are most fully displayed. Its disks (fig. III., 4) attain not only a much larger diameter, but a relatively greater thickness, than those of either of the "simple" species; the annulations which mark their surfaces are as complete in their central as in their peripheral portions; their superficial

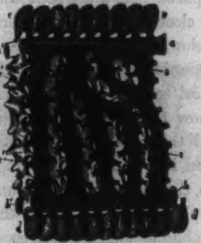
---

Phil. Trans., 1856, Plate IV., fig. 13.

chamberlets have an elongated form (fig. III., 3, *a*), and their margins exhibit, even in the smallest (or youngest) specimens, *multiple* series of pores (fig. III., 1), indicative of that complicated arrangement of the cavitary system which I described minutely in my former Memoir.

The meaning of that arrangement is best understood by an examination of the sarcodic body left after the decalcification of the disks, which are modelled, as it were, upon it. The accompanying representation (copied from Plate IV., fig. 4 of my former Memoir) shows two annular cords, *a a′*, *b b′*, in each annular zone, instead of the single cord of *O. duplex;* and between these two cords is interposed a series of columnar sub-segments, *e e*, *e′ e′*, whose bases and summits (so to speak) are brought into continuity by them. It is of the interposed shell-substance that lodges these columnar sub-segments, that the thickness of the disk (fig. III., 2) is chiefly made up; and this is obviously in relation with the length of the columns. Between each annular cord and the nearest surface of the disk, is a series of sub-segments, *c c*, *d d*, which occupy the elongated chamberlets whose partitions are marked externally by radial lines that cross the several annuli (fig. III., 3, *a*), as in *O. tenuissima.* These partitions, however, being complete, the chamberlets have no lateral communication with each other; neither do they communicate by means of radial passages with those of the annuli internal and external to them. But each has a passage at either end through its own floor, which allows a stolon-process to pass from the sub-segment which it lodges to the annular cord beneath; each sub-segment being, therefore, in connexion with the two annular cords, and forming, as it were, a bridge between one and another, as shown in fig. IV. Except through the intermediation of these sub-segments, the annular cords of the successive zones have no connexion with each other; but the intermediate columnar sub-segments of each annulus communicate with those of the next by

Fig. IV.



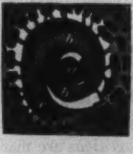
Portion of sarcodic body of *Orbitolites complanata:*—*a a′*, *b b′*, the upper and lower annuli of two concentric zones; *c c*, the upper layer of superficial sub-segments, and *d d*, the lower layer, connected with the annular cords of both zones; *e e* and *e′e′*, intermediate columnar sub-segments of the two zones.

oblique stolon-processes, that pass off alternately at regular intervals from the two sides of each column, traversing the annular septa; and the orifices of the passages in the last-formed septum, through which these stolon-processes extend themselves outwards, are seen as multiple series of pores on the margin of the disk (fig. III., 1).

The vertical section of the calcareous disk given in fig. III., 2, shows the separation of the two superficial planes of chamberlets by the interposition of the shelly fabric that gives lodgment to the intermediate sarcodic columns; while at 3 is shown diagrammatically, on a larger scale, the cavitary system of the disk, with the communication between its several parts. At *a* are seen the chamberlets of the superficial planes, which are completely closed in when not abraded; and these are shown in vertical section, above and below, at *b*, while at *c* are seen their floors, each having a pore at either end, which communicates with the annular canal beneath. The annular canals are seen at *d* in vertical section, and at *d′* and *d″* as laid open in horizontal section; the former showing how they cross the tops of the cylindrical chamberlets of the intermediate stratum, and the latter (taken a little nearer the surface) showing the manner in which they open into the pores leading to the superficial chamberlets. In the lower part of the figure, the intermediate stratum is traversed by two horizontal sections in slightly different planes, cutting across the cylindrical chamberlets, and showing the two series of oblique stolon-passages by which the chamberlets of successive annuli communicate with each other.

The nuclear mass which occupies the centre of the disk consists, as in *O. duplex*, of a "primordial segment," surrounded by a "circumambient segment," and this last (fig. V., *b*, *b*) puts forth a set of stolon-processes from its entire periphery, each of which gives origin to a columnar sub-segment; so that a complete annulus is at once constituted, thus establishing the *cyclical* plan of growth *from the very first.*

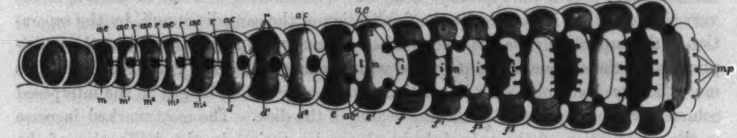
Fig. V.



The collection of specimens of *O. complanata* made on the Fiji reef contains disks of all sizes ranging from 0·04 inch to nearly 1 inch; and even in the smallest of them, whose nucleus is surrounded by only two or three annuli, the immediate assumption of the completed plan is marked by the multiplicity of the series of marginal pores. But while this may, I think, be unquestionably regarded as the *typical* condition of the species, the collection also includes an abundance of disks whose peripheral portion is characteristically "complex," whilst their central portion is no less characteristically "simple;" the passage from the one plan of growth to the other taking place at no fixed stage, but being made sometimes earlier, sometimes later, for the most part gradually, but sometimes abruptly, as I indicated in my former Memoir (§§ 57, 58).

I can now trace out more distinctly than before the successive phases of this transition; and can show how exactly the fundamental characters of *O. marginalis* and *O. duplex* are reproduced in what may be called the childhood and youth of those "sub-typical" examples of *O. complanata*, which, instead of beginning life on the "complex" plan, only attain the more elevated type in adult age. These phases are exhibited in the following vertical section (fig. VI.) taken in the radial direction, which, though representing them somewhat diagramatically, is true to nature in every essential particular. Of the successive zones traversed by the sectional plane between the circumambient chamber, *c c′*, which passes round the primordial chamber, *p*, the first five, m, m^1, m^2, m^3, m^4, are formed exactly on the type of those of *O. marginalis*; each chamberlet being connected laterally with the other chamberlets of its own zone by a single annular canal, *ac*, and with the chamberlets of the zones internal and external to it by the radial stolon-passages, *r r*. These are succeeded by three zones, d, d^1, d^2, formed upon the "duplex" plan; each chamberlet having, as in the preceding case, but a single annular canal, *ac*, but communicating with the chamberlet of the annulus external to it by two oblique radial stolon-passages, as shown at *r*. Thus, then, if the growth of this disk had been checked at the fifth zone, m^4, its margin would have presented the single row of pores characteristic of *O. marginalis*; and if at the eighth zone, d^2, it would have shown the double row characteristic of *O. duplex*. But in the next zone, *e*, the annular canals *ac*, *a′c′*, are duplicated, each of them sending off a stolon-passage into the next annulus. In this and the succeeding zone, *e′*, however, there is no separation between the superficial portions, *s s′*, of the chamberlets, and their median portions, *m m*; and this continuity, here transitory, shows itself as the typical character of the chamberlets of the fossil *O. complanata* of the Paris basin. But in the existing *O. complanata*, a separation comes to be effected, as shown in the succeeding zones, f, f^1, f^2, f^3, by horizontal extensions of the septa *i i*, that are interposed between the median portions of the chamberlets, so as to form the floors of the superficial layers; while at the same time there is a shifting of their relative positions, so that the superficial chamberlets, *s s*, *s′ s′*, instead of lying over or under the median portions, *m m*, alternate with them, and are entirely

Fig. VI.



cut off from any other communication with them than that which is afforded by the annular canals, with which each superficial chamberlet communicates at either end, by a passage which—thus traced out—is seen to be homologous with one of the double radial stolon-passages of *O. duplex*, and therefore with the single radial passage of *O. marginalis*. The septa, *i i*, which divide the median portions, *m m*, of the successive annuli, are traversed by numerous passages, which, from the lateral obliquity of their direction (fig. III., 3, *f*, *f*), scarcely show themselves in a radial section, although they debouch at the edge of the last annulus as marginal pores, *mp*.

Notwithstanding this progressive complication in the structure of the shelly disks, there is no appearance of any corresponding specialisation in the character of the sarcode body: that of the typically "complex" form showing no other advance upon the very simplest, than is marked by the duplication of the sarcodic annuli, by the separation of the superficial from the intermediate columnar sub-segments, and by the multiplication of the oblique stolon-processes which connect these last with each other, this multiplication being obviously in relation with the increasing length of the interposed columns, which shows itself in the thickening of the disk. The most marked increase in the complication of the animal body obviously consists in the duplication of the sarcodic annuli; and this may be readily conceived as a longitudinal splitting of each cord into two, with a persistence of adhesion at intervals, so that the two semi-annuli, when carried apart from one another by the interposition of the intermediate stratum, remain connected by the vertical sarcodic columns which traverse that stratum. The sub-segments which occupy the upper and under layers of surface-chamberlets are clearly shown, by their relation to the sarcodic annuli, not to be new productions, but to be homologous with the upper and under halves of the sub-segments that occupy the columnar chamberlets of the "simple" type; that homology, however, being so masked in the typically "complex" form by the displacement they have undergone, that it could not have been certainly recognised, but for the occurrence of those subtypical forms which enable the passage from the most "simple" to the most "complex" to be continuously traced-out.

I have been unable, after the most careful examination of the sarcodic bodies of *O. duplex* and *O. complanata*, to discover any indication that this progressive complication in the disposition of their parts, is accompanied by any such structural modification as might lead to the suspicion of differentiation of function. On the contrary, I find their substance to be everywhere of the same elementary character, consisting of a homogeneous protoplasm, that contains a large number of spherules of from $\frac{1}{3000}$th to $\frac{1}{8000}$th of an inch in diameter, sometimes crowded closely together, in other instances more dispersed, as shown in fig. 3, Plate IV. of my former Memoir (Phil. Trans., 1856). These spherules, when subjected to pressure, break up into a number of pellucid corpuscles, which are usually of from $\frac{1}{15000}$th to $\frac{1}{20000}$th of an inch in diameter. The absence of these spherules is a marked feature of difference in the protoplasmic body of *O. tenuissima*; on the other hand, I have not met in the higher types with those nuclear (?) bodies which I have recognised in the abyssal species (see p. 556).

The homogeneousness of the entire sarcodic body, even in the largest and most complicated forms of *O. complanata*, appears to be further indicated by the fact, that in specimens taken alive and preserved in spirit, the peripheral portion of the cavitary system is invariably found empty; the sarcodic body, corrugated by the action of the spirit, being drawn together towards the central portion of the disk through very narrow passages of communication, which could only happen with a substance of which every part is free to move upon every other. Looking, also, to the manner in which the entire organism receives its nourishment through the marginal pores, and to the entire absence of any special means for the distribution of that nourishment, I think it may be fairly assumed that such a protoplasmic circulation goes on throughout life, as must produce a continual change in the substance of every individual sub-segment.

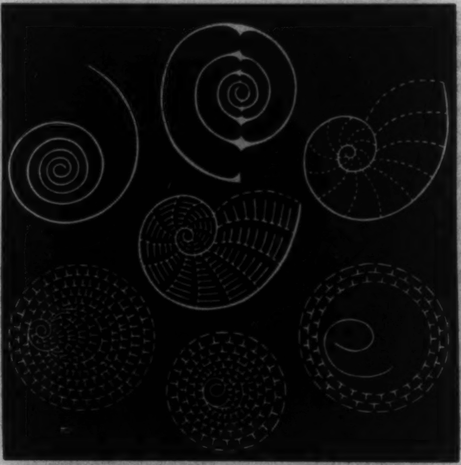
Additional evidence of this homogeneousness is afforded by the two following facts: first, that in specimens which live under conditions peculiarly favourable to their enlargement, out-growths of irregular shape, but always possessing a regular internal structure, are put forth from any part of the disk (see "Challenger" Report, Plate VII.); and second, that, as in *O. tenuissima*, every part seems equally capable of reproducing the entire disk on its characteristic plan.

Evolutionary History of the Orbitoline Type.

Thus by the combined study of *O. tenuissima* and of sub-typical examples of *O. complanata*, we are enabled to work out the whole evolutionary history of the Orbitoline type, from its simplest to its most complex form. For there can, I think, be no reasonable doubt, that the succession here presented to us in the consecutive phases of two lives, has been the genetic history of this type; which, originating in the simplest "jelly-speck" that could form a shelly chamber, first assumed the form of a spirally-coiled undivided tube (*Cornuspira*, fig. VII., 1); then of a spire interrupted at intervals by imperfect partitions (*Spiroloculina*, 2); then of a flattened spire crossed by complete septa traversed by stolon-passages (*Peneroplis*, 3); then of a progressively widening spire, whose chambers are divided into chamberlets (*Orbiculina*, 4); then of a chamberletted disk of one storey, commencing as an orbiculine spire, but subsequently increasing by annular additions (*Orbitolites tenuissima* and *O. marginalis*, 5); then of a chamberletted disk, whose origin still shows in its slight eccentricity a trace of the primordial spire, and whose single storey has, so to speak, two rows of windows (*Orbitolites duplex*, 6); and lastly, of a "complex" disk, whose growth is cyclical from the beginning, and whose upper and lower superficial planes are separated by the interposition of an intermediate columnar structure between the duplicated annular stolons (*Orbitolites complanata*, 7). This last would seem to be the culmination of the type, which, while attaining a considerable size, has never shown, so far as is at present known, any tendency to pass into a higher form. Indeed, the typical forms of the existing *O. complanata* are in one small particular (as already shown, p. 565) more specialised than the fossil forms that were so remarkably abundant in the Middle Tertiary epoch.

It is a remarkable feature of this case, however, that all the forms through which the highest *Orbitoline* type is thus shown to have passed, continue to hold their ground at the present time, as the characteristic representatives of less specialised groups. There being every reason to regard *Cornuspiræ*, *Peneroplides*, and *Orbiculinæ* as distinct races, propagating themselves genetically without any essential modification, it can scarcely be supposed that every one of them is a "potential" *O. tenuissima*. So, again, as we find *O. marginalis* and *O. duplex* living and propagating under the very same conditions as *O. complanata*, I cannot regard these "simple" forms of the Orbitoline type, each of which has its characteristic plan of structure and limit of growth, as potentially "complex;" notwithstanding the exact repetition of their plans in the early stages of certain examples of the higher type. For I have never observed in the largest and best developed examples of *O. marginalis* and *O. duplex* the least tendency to assume the "complex" form; on the other hand, I have frequently found their last formed annuli deficient in internal partitions, as if their productive power had exhausted itself. It would seem, therefore, more just to

Fig. VII.



regard those sub-typical examples of *O. complanata*, which exhibit the transition I have described from the "simple" to the "complex" plan of structure, not as advanced forms of either of the two "simple" species, but as retarded forms of the highest; and a clue to the conditions of that retardation can, I think, be found in the marked inferiority I have invariably observed in the size of the original nuclear mass of these individuals. I drew attention in my former Memoir (§ 44) to the remarkable range of dimension which this mass exhibits, when a considerable number of specimens are examined; and showed that the cavity of the "primordial" and "circumambient" chambers in one individual must have been more than a hundred times as large as that of another. Now the result of the far more extended comparison of specimens which the "Challenger" collection has enabled me to make, is, that while the "nucleus" of the typical *O. complanata* (in which the cyclical plan of growth, and the "complex" structure, show themselves from the very first) is always many times larger than that of either *O. marginalis* or *O. duplex*, the "nucleus" of its sub-typical forms always bears a very close accordance in size to that of *O. duplex*, which it resembles also in the one-sided pullulation of the first sub-segments from the circumambient segment, rendering the earlier zones more or less incomplete, and the position of the "nucleus" slightly eccentric. Whether these forms genetically propagate themselves as a *race*, perpetuating an earlier stage of the evolution of the perfected type, or are merely *individuals* which have begun life as "starvelings" that do not inherit the characteristic vigour of the type, I have no adequate ground for even surmising; being only able to affirm this, that as there is no kind of constancy in the stage of growth at which the "simple" plan gives place to the "complex," there is nothing to justify a specific differentiation of this sub-typical variety. That its peculiarity may depend upon conditions less favourable to the full development of the type, seems to be indicated by the fact that, whilst the largest and most typical specimens of *O. complanata* were found in the rock-pools on the summit of the Fiji reef, where they would have the highest temperature and the greatest abundance of food, the sub-typical specimens presented themselves chiefly in the collection made by the dredge at 18 fathoms' depth.

Theory of Descent.

I propose, in the last place, briefly to examine the bearing of the remarkable case of "descent with modification," which I have thus detailed, upon the general "Theory of Descent" and of the "Origin of Species."

Those who find in "natural selection" or the "survival of the fittest" an all-sufficient explanation of the "origin of species," seem to have entirely forgotten that before "natural selection" can operate, there must be a range of varietal forms to select from; and that the fundamental question is (as Mr. DARWIN himself clearly saw, at any rate in his later years), *what gives rise to variations?* No exercise of "natural selection" could *produce* the successive changes presented in the evolutionary history of the typical *Orbitolites*, from *Cornuspira* to *Spiroloculina*, from *Spiroloculina* to *Peneroplis*, from *Peneroplis* to *Orbiculina*, from *Orbiculina* to the "simple" forms of *Orbitolites*, and from the "simple" to the "complex" forms of the last-named type. And as all these earlier forms still flourish under conditions which (so far as can be ascertained) are precisely the same, there is no ground to believe that any one of them is better fitted to survive than another. They all imbibe their nourishment in the same mode; and no one type has more power of going in search of it than another. That they are all dependent on essentially the same conditions of temperature and depth of water, is shown by their occurrence in the same marine areas. That they all equally serve as food to larger Marine Animals, can scarcely be doubted; and it is hardly conceivable that any of their devourers would discriminate (for example) between the disks of a large *O. marginalis*, a middle-sized *O. duplex*, and a small *O. complanata*, which even the trained eye of the Naturalist cannot distinguish without the assistance of a magnifying-glass.

To me, therefore, it appears that the doctrine of "natural selection" can give no account of either the origin or the perpetuation of those several types of Foraminiferal structure which form the ascending series that culminates in *Orbitolites complanata*. On the other hand, there seems traceable throughout that series a *plan* so definite and obvious, as to exclude the notion of "casual" or "aimless" variation. Between the simple spirally-coiled sarcodic cord of a young *Cornuspira*, and the discoidal body of an *Orbitolite*, with its thousands of sub-segments disposed with the most perfect symmetry, and connected together in most regular and uniform modes, who (in the absence of the intervening links) would have suspected any genetic relation—who would have ventured to construct a pedigree? And yet we find the gradations from the one to the other to be not only most complete, but often significant of further progress; many of the changes being such as seem to have no meaning except as anticipations of greater changes to come. Thus, the slight constrictions that show themselves in the first spiral coil of *O. tenuissima* (Plate 38, fig. 3) are what constitute the essential difference between the spire of *Cornuspira* and that of *Spiroloculina*; marking an imperfect septal division of the spire into chambers, which cannot be conceived to affect in any way the physiological condition of the contained animal, but which foreshadows the complete septal division that marks the assumption of the Peneropline stage. Again, the incipient widening-out of the body, previously to the formation of the first complete septum, prepares the way for that great lateral extension which characterises the next or Orbiculine stage; this extension being obviously related, on the one hand, to the division of the chamber-segments of the body into chamberletted sub-segments, and, on the other, to the extension of the zonal chambers round the "nucleus," so as to complete them into annuli, from which all subsequent increase shall take place on the cyclical plan.

In *O. marginalis*, the first spiral stage is abbreviated by the drawing-together (as it were) of the "spiroloculine" coil into a single Milioline turn of greater thickness; but the Orbiculine or second spiral stage is fully retained.

In *O. duplex*, the abbreviated Milioline centre is still retained, but the succeeding Orbiculine spiral is almost entirely dropped out, quickly giving place to the cyclical plan.

And in the typical *O. complanata* the Milioline centre is immediately surrounded by a complete annulus, so that nothing remains of the original spire save the one turn of the circumambient segment.

So, in the passage from the "simple" to the "complex" type, we have a remarkable anticipatory step in *O. duplex*, which can scarcely be supposed itself to derive any advantage from the substitution of a double for a single row of communications between the annuli, since *O. marginalis* flourishes equally well with its single row; but which forms, so to speak, a stepping-stone to a higher grade.

Everything in this history, then, shows *a well-marked progressive tendency along a definite line towards a highly specialised type of structure in the Calcareous fabric;* and this without any corresponding departure from the original homogeneity of the Animal body which forms that fabric. And as being, so far as I know, altogether unique in these peculiarities, I venture to offer this study of a humble protoplasmic organism, brought up from an ocean-depth of nearly two miles, to the consideration of those who believe with Sir James Paget, that "the highest laws of our [biological] science are expressed in the simplest terms in the lives of the lowest orders of Creation."

Explanations of Plates.

PLATE 37.

Structure of Calcareous Disk of *Orbitolites tenuissima.*

Fig. 1. Surface of young disk, showing its eccentric spiroloculine "nucleus," giving origin to successive zones of orbiculine chamberlets, which gradually increase in breadth with the opening-out of the spire, until they extend completely round the nucleus; after which the successive additions are made on the cyclical plan, as concentric annuli. Magnified 25 diameters.

Fig. 2. A portion of three peripheral annuli, enlarged to 64 diameters, and partially laid open by the removal of the superficial lamella, so as to show the two annular septa, *aa*, *bb*, the chamberlets, *c*, separated by radial partitions, and the annular gallery, *d*, into which all the chamberlets open at their peripheral extremities.

Fig. 3. Vertical section of three annuli of the disk, taken in the radial direction, so as to traverse the chamberlets lengthways; *a*, *a*, junctions of two annuli, with

the annuli external to them; *b*, *b*, *b*, annular galleries traversing the septa between the chamberlets. At *a*, *a*, are seen the openings through which the sarcodic cords that occupy the annular galleries send radial extensions into the chamberlets of the succeeding annuli. Magnified 64 diameters.

Fig. 4. Internal aspect of a small portion of an annulus detached by fracture; showing the entrances to the chamberlets of that annulus through the septal plane. Magnified 64 diameters.

Fig. 5. External or peripheral aspect of a portion of a marginal annulus, showing the passages through its septal plane, as marginal pores elongated in the plane of the disk. Magnified 64 diameters.

Fig. 6. Portion of a disk, whose remainder, with the "nucleus," has been lost by injury previously to the formation of the last two annuli, which have extended themselves along the fractured margin, and into the nuclear space. Magnified 15 diameters.

Fig. 7. Incipient production of an entirely new disk, with regularly concentric annuli, from a fragment of the peripheral portion of an old one. Magnified 15 diameters.

PLATE 38.

Structure of Sarcodic Body and Calcareous Disk of *Orbitolites tenuissima*.

Fig. 1. Sarcodic body of the central portion of the disk; showing the primordial segment giving off the spiroloculine coil, the sixth turn of which, *a*, begins to open out into a peneropline form, afterwards becoming divided into rows of orbiculine sub-segments, which are connected together laterally by the continuity of the sarcodic body through the gallery at the outer end of each row, and radially by the stolon-processes that pass through the septal passages, from the gallery of the inner row into the chamberlets of the outer. Nuclear (?) corpuscles are seen irregularly distributed through the sarcodic substance. Magnified 75 diameters.

Fig. 2. Nuclear (?) bodies, as seen under a power of 450 diameters.

Fig. 3. Section of first-formed portion of the disk, laying open the primordial chamber, *a*, and the spiroloculine chambers, partially divided as at *b*, which coil round it. Magnified 125 diameters.

Fig. 4. Portion of the sarcodic body shown in fig. 1, enlarged to 125 diameters, to show the distribution of the nuclear (?) corpuscles:—*a*, expanded extremity of the last spiroloculine coil; *b*, *b*, *b′*, *b′*, portions of preceding coils, crowded with nuclear (?) corpuscles; *c*, orbiculine sub-segment, with five corpuscles; *d*, *d*, *d*, *d*, orbiculine sub-segments, each with one or with two corpuscles.

Fig. 5. Central portion of the calcareous disk, as seen by transmitted light;—*a*, expanded chamber formed by the termination of the spiroloculine coil, and

closed-in by a peneropline septum traversed by four passages; *b*, second chamber, divided by radial partition into orbiculine chamberlets; *c*, third chamber, not here separated from the second by a septum, and having only one radial partition; *d*, *d*, fourth chamber, having at *d'*, *d'*, lateral extensions which begin to enclose the spiroloculine coil; *e*, *e*, fifth chamber, with lateral extensions, *e'*, *e'*, proceeding still further backwards; these chambers, and those that succeed them, divided by radial partitions into orbiculine chamberlets. Magnified 75 diameters.

[illegible] chamber, divided by radial partitions into [illegible] chamberlets. [illegible] Chambers not well separated [illegible] and having [illegible] one radial partition [illegible] chamber, [illegible] which begin to enclose the [illegible] lateral [illegible] and those that succeed them divided by radial partitions into numerous chamberlets. Magnified [illegible] diameters.

[illegible]

XV. *On the Affinities of* Thylacoleo.

By Professor Owen, *C.B., F.R.S., &c., Superintendent of the Natural History Department, British Museum.*

Received January 25,—Read February 1, 1883.

[Plates 39–41.]

In a former Paper on *Thylacoleo*[*] was summed up what I then inferred from the fossil remains of the species "*carnifex*" which had reached me at that date, but acquiescence in those conclusions seemed, in the opinion of some contemporary Palæontologists, to require further evidence. I have, accordingly, omitted no opportunity of obtaining such, and the fossils so acquired form the subject of the present communication.

The locality which promised success in this quest was the limestone district of Wellington Valley, New South Wales, from one of the caves of which the first evidence of *Thylacoleo* had been obtained.[†]

And, here, I have to express my deep obligations to the Legislature of New South Wales for the Grants liberally voted for the further exploration of the caves and brecciated fissures of that district, and my acknowledgments of the friendly support given to my representations by the Premier, Sir Henry Parkes. The direction and supervision of these explorations were confided to the accomplished and able Curator of the Australian Museum, Sydney, Ed. V. Ramsay, F.L.S., to whom I am indebted for prompt transmission of the subjects of the present Paper, included in the results of his mission.

Dentition of the upper jaw of Thylacoleo carnifex.—Of the first or laniariform incisor the base only of the crown was the subject of fig. 1, 2, 3, Plate 11, p. 217, of the Paper above cited (1871). A detached crown of what I then inferred to have formed part of the homologous tooth is the subject of fig. 7 and 8 of Plate 11 (Paper, 1871). I have now the upper jaw with the entire dentition (Plate 39, fig. 1), of which it seems necessary to add to former figures the palatal view only for comparison with fig. 3 of Plate 11 (Paper of 1871).

---

[*] "On the Fossil Mammals of Australia": Part IV., Phil. Trans., 1871, p. 213.

[†] By the then Surveyor General of Australia, Colonel Sir Thomas Mitchell, C.B., discoverer of the fertile region which he named after his great Commander. See Appendix to his 'Three Expeditions into Eastern Australia,' 8vo., vol. ii., 1838.

The foremost tooth (Plate 39, fig. 1, i_1) shows an exserted crown, 1 inch 3 lines in length, curved with the convexity forward, subcompressed, conical, pointed, obtuse anteriorly, trenchant behind where the enamel forms a finely serrate ridge; it is in shape and size a tooth suggestive of powers of penetration and prehension. It is deeply inserted by a stout cement-clad fang, indicative of limited growth. The entire length of the tooth, following the curve, is 2½ inches.

The second tooth, (ib., ib., i_2) projects behind and partly mesiad of the base of the first, its crown is but 5 lines in length; other dimensions are shown in the figure. The working surface is bevelled off, before and behind, to a low ridge.

Next to this tooth and partially overlapping the hind and outer part of its crown is that of a larger trenchant tooth, i_3, 7 lines in longitudinal, 5 lines in transverse diameters, but barely exceeding the second tooth in height.

This is followed by a fourth, p_1, about the size of the second, i_2. Its crown is partly overlapped by the larger tooth, i_3; it is also subtrenchant lengthwise.

External to the hinder part of p_1, and about half the size, projects the crown of a tubercular tooth, p_2; it is immediately followed by a sixth tooth, p_3, of similar shape and size. This tooth is partly overlapped externally by the fore end of the great carnassial tooth, p_4.

The homologies indicated by the symbols of the five teeth crowded between i_1 and p_4 may be questioned, but that of the latter with the trenchant premolar in existing phytophagous Diprotodonts is plain. In plate 100, pp. 381–394 of the undercited work,* the eight chief modifications of the comparable Diprotodont dentition in existing Marsupials are described and figured. Of these the genera *Hypsiprymnus* and *Phascolarctos* offer the nearest approach to *Thylacoleo* in the proportions of antero-posterior to vertical extent of the crown of p_4. But the size of this tooth in those existing genera is much less relatively to the other teeth, especially to the bruising molars, four on each side of the upper, as of the lower jaw, which in them follow the trenchant premolar. In those genera, as in *Macropus*, *Petaurus* and *Phalangista*, three close-set incisors are lodged in the premaxillary; and, in *Macropus*, the third incisor is as much larger than the second, as is the third tooth (Plate 39, fig. 1, i_3) in the series of upper teeth in *Thylacoleo*.

In *Phascolarctos* and *Hypsiprymnus* a minute canine projects from the maxillo-premaxillary suture with a well-marked interval between the incisors in front and the trenchant premolar behind. In *Petaurus* and *Phalangista Cookii* two small premolars, p_3, p_2, precede the tooth p_4, which is in contact with the foremost of the four crushing molars.

With the five teeth, therefore, preceding the trenchant premolar, in the above-cited existing Diprotodonts may be homologized, in the aggregate, the five teeth between the foremost tooth, i_1, and the carnassial, p_4, in *Thylacoleo*. But to which of them the term canine may be assigned is doubtful. Relative size might weigh with the largest of these intermediate teeth, i_3, but its trenchant character is repeated in the third incisor of the existing Kangaroos; it is not a cuspidate tooth as restored in outline at *c*, in Plate 14 of the Paper of 1871. I have nothing to alter or add to former descriptions of p_4 and m_1 (ib., ib.). In existing Diprotodonts the latter tooth has a broad tuberculate or ridged masticatory crown, and is followed by three similar molars, absent in *Thylacoleo*.

---

* 'Odontography,' 8vo., 1840.

Of the extreme modification of the Diprotodont type for carnivorous work I hold the opinion expressed in the former Paper (1871), and have only to add that the retention of the seemingly functionless teeth, i_2–p_3, crowded together in the upper jaw, is significant of a principle underlying the adaptive explanation.

Dentition of the lower jaw of Thylacoleo.—In the portions of mandible of *Thyl. carnifex*, figured in Plates 12 and 13 of the Paper of 1871, the dental formula was inferred, as in that of the upper jaw, from sockets of teeth. I am now able to submit three views of the entire dentition of a fossil mandible (Plate 39, fig. 2; Plate 41, figs. 1 and 2) discovered in contiguity with the subject of fig. 1, Plate 39.

The foremost laniariform tooth, i_1, repeats the shape and size described (pp. 226, 227) and figured (Plate 13, figs. 4–7, Paper of 1871) from a cast transmitted to me in 1870, of a tooth in the Museum of Natural History, Sydney, which was obtained by Mr. KREFFT from "a breccia cavern, Wellington Valley"; and its characters might well condone the conjecture that it was a feline canine tooth.

Two small teeth (Plate 39, fig. 2, p_2, p_3) are wedged in between the foremost tooth, i_1, and the carnassial, p_4.

In *Phalangista vulpina* one such tooth follows the front incisor; in *Phal. Cookii* there are two; in *Petaurus* there are three denticles between the incisor, i_1, and the premolar, p_4. To two of such seemingly functionless teeth those marked p_2 and p_3, in Plate 39, fig. 2, and Plate 41, figs. 1 and 2, may be homologous. Their interest lies, as in their homotypes in the upper jaw, in the manifestation of a diprotodont dentition under its extreme functional modification in the great extinct Marsupial Carnivore.

Two sockets, indicated by p_2 and p_3, in the fossil figured in Plate 12, figs. 2 and 3, (1871), but which might have lodged the two roots of a single tooth, are now demonstrated to have held two small close-set teeth, of which the hindmost is hidden from outer view by the forepart of the carnassial, p_4. The foremost, p_2, immediately following i_1, is more than twice the size of p_3, and has a cuspidate crown (Plate 39, fig. 2); but it is a dwarf by the side of the laniariform tooth, i_1. To former descriptions of this tooth there seems nothing to add to the present demonstration of its place in the dental series.

The tooth, m_1, succeeding the carnassial, repeats in general character that described (p. 224) and figured (Plate 13, fig. 2, m_1, 1871) from a photograph. The difference in wear and the slight one in size may indicate the present fossil to have come from an older and somewhat (sexually ?) larger *Thylacoleo.* The apex of the anterior lobe has been worn off, and the lower hind lobe shows abrasion; but there is as little approach in relative size and conformation of crown in the present thylacolean *m* 1 to that tooth in the phytophagous Diprotodonts (Plate 41, figs. 3 and 4) as was indicated by the thylacolean subject which first came to my hands.

The tooth, *m* 2, as indicated by its socket in Plate 14 (1871), is of the same relative size, but with a more acuminate crown than is indicated by the conjectural outline there given.

The maxillary and mandibular fossils here described and figured add the entire dentition of *Thylacoleo carnifex* to the series of mammalian modifications of the dental system with which Comparative Anatomy is now enriched; and they afford sure grounds for physiological deductions as to the nature and habits of the extinct Marsupial.

Antibrachial bones of Thylacoleo.—Of the bones and portions of bone referable by size to this genus and discovered in the same cave with the jaws and teeth last described are those of the fore-arm (Plate 40), of which the ulna (fig. 4) lacks only two inches of its distal end, according to the proportions of that bone in the larger Felines: this comparison is made from its being associated with an entire radius (ib., fig. 1) of the same length as that of the Lion: both fossils form part of the same limb of the leonine Marsupial.

The articular surfaces in these fossils are as closely adapted to the divers movements of a fore-arm required for the application of the paw of a carnivore as in the Felines.

The proximal end of the radius is occupied by an articular surface (ib., fig. 2) in two continuous portions, the larger and terminal one (fig. 3, *a*) being moderately concave for adaption to the radial condyle of the humerus, the smaller convex surface (ib., *b*), bending down on the inner or ulnar border for articulation with the outer or radial concavity (fig. 5, *b*), continued from the larger and deeper trochlear surface (ib., *a*), near the humeral end of the ulna.

The proximal or humeral cavity of the radius is not circular as in herbivorous Marsupials, but is less oblong than in *Leo;* it is similarly continued upon a thick convex border, extended to form the surface *b*, fig. 3.

The shaft of the radius describes the same slight curve "radiad," or on the outer side, and maintains the same nearly uniform breadth to the distal expansion, as in the Lion. The radial, or free, border is similarly obtuse; the opposite border (*d*) is for the most part roughly trenchant. The process (fig. 1, *c*) for implantation of the *brachialis externus* muscle holds the same relative position to the proximal end as in *Leo.* At the expanded distal end the elongate tuberosity (*e*) above the produced radial or outer angle for the carpal joint shows the same oblique groove for the tendon of the *extensor carpi radialis.* The tuberosity (*f*) answering to that giving insertion to the tendon of the *supinator longus* in the Lion, is nearer the ulnar angle of the distal expansion, instead of rising midway between the terminal angles: and here I may remark that the Felines agree with the Marsupials in the presence of this muscle. In all minor modifications the leonine characters are closely repeated in the present fossil radius.

The same general correspondence of structure prevails in the ulna (fig. 4). The olecranon (*c*) offers the same development, with tuberous and ridged indications for adequate implantation of the powerful extensors of the fore-arm: it is relatively longer, but with rather less breadth than in *Leo*. The proximal articular surface has the same trochlear character (*a*) and passes uninterruptedly, but with a similar defining line, into the concave surface (fig. 5, *b*) for the corresponding side of the head of the radius. The adaption of these joints for free pronation and supination, as well as flexion and extension of the fore-paw, is as strongly marked in *Thylacoleo* as in the similarly-sized placental Felines. The few noticeable modifications indicate the derivative relation to the inplacental group.

In the existing Diprotodont Marsupials, whether climbers, flyers, burrowers or leapers, the bones of the fore-arm are freely articulated for both rotatory and flexile movements, a power which has been suggested to relate to manipulations of the nursing pouch; therefore, to be needed by the Kangaroo group as well as the rest. But in none, save the Wombat, does the proportion of the olecranon come near to that in *Thylacoleo*. The modifications of the radius and ulna for burrowing actions present differences, in number and kind, from those in *Thylacoleo* which need only a glance at the skeleton of *Phascolomys* to be appreciated.

In other Diprotodonts, especially the species *Macropus major*, for example, nearest in size to *Thylacoleo*, the olecranon is not continued beyond the trochlear cavity to the extent of that joint longitudinally: the shaft of the ulna is relatively longer and much more slender. The radius, with a circular proximal end, gives a smaller and less definite lateral articular surface to a concomitantly smaller external ('radial') offset from the trochlear articulation: the shaft of the radius is also relatively longer and more slender, and is proportionally less expanded at the distal end than in *Thylacoleo*.

Claw-phalanx of Thylacoleo.—Passing over evidences of carpal and metacarpal fossils, my remarks will, here, be limited to the characters of the terminal or ungual phalanges.

Fossil claw-bones are not few from the Thylacolean cavern, and these in shape and structure add instructive evidence of the nature of the quadruped to which, by their size, they may be attributed. By these characters a phalanx of a fore-paw may be selected: the talon which such bone supported and wielded was fully as large as that of the Lion, and indicates that it was sub-compressed, decurved and pointed.

The basal articular surface (fig. 7, *a*) shows a pair of vertical concavities divided by a mid-ridge: it occupies the breadth and greater part of the height of the base, leaving about an equal but small extent of non-articular tuberous insertional portion above and below the trochlear joint.

But the most instructive part of the phalanx is the extension from the upper and lateral borders of the base of a bony sheath (fig. 6, *b*), which overarches the proximal three-fourths of the claw-bearing part (*c*): this sheath is also continued from the sides of the broad, somewhat flattened under portion of the articular division of the phalanx, which terminates (fig. 8, *d*) where the compressed claw extends freely forward. The under surface (fig. 7) of the sheath-supporting division of the phalanx is perforated by a pair of canals, which transmitted the blood-vessels and nerves to the formative and reproductive organ of the talon.

I have not found any instance of such sheath claw-phalanx in the existing or extinct kinds of diprotodont Marsupials, other than *Thylacoleo*.

The placental Mammals which possess such claw-sheath are amongst the carnivorous, and, most conspicuously, the Feline species; also certain Edentates, more especially the great extinct Megatherioids.

The chief difference, in these placentals, is that the articular surface, in Felines, ends nearer the lower or palmar surface of the joint, which is overtopped by the prominence for insertion of the retractor tendon of the claw; while in Edentates the articular surface leaves a larger proportion of the under part of the base of the phalanx free and tuberous for insertion of the powerful muscles which deflect the claw.[*] In all Edentates the claw-bearing part of the sheathed-phalanx is relatively longer, thicker, and commonly less acute than in Felines.

In this comparison the ungual phalanx of *Thylacoleo* much more closely resembles that of *Felis Leo* or *Felis Tigris*.[†]

Mandible of Thylacoleo.—I finally submit a description and figures (Plate 41) of the fossil mandible with the Thylacoleon dentition, as the osseous evidence testifying most directly to the matter at issue.

Plate 41, fig. 1, gives the outside view of a mandible of *Thylacoleo carnifex*, in which a carnivorous modification of the dentition has been engrafted, as in the older extinct form *Plagiaulax* (ib., fig. 5), on a Marsupial and Diprotodont type.

In comparison with the mandible of the Koala (*Phascolarctos*, Plate 41, fig. 3) and Potoroo (*Hypsiprymnus*), which are selected by Professor FLOWER, F.R.S.,[‡] as most nearly resembling that of *Thylacoleo*, may, first, be noted in *Thylacoleo*, fig. 1, the relative shortness of the dentigerous part of the mandible to its depth, especially at the fore end, and the outswelling wall of the socket of the great carnassial premolar (ib., fig. 1, *p* 4) : next, the relative extent and depth of the depression (*d*) for the insertion of the temporal, or great biting, muscle. The outline of the termination of the coronoid process (*b*) is given on the authority of Mr. RAMSAY, from other and fragmentary portions of Thylacolean mandibles. The upper border of the process extends backward at a more open angle than in the Potoroo or Koala (ib., fig. 3), and to an extent beyond the articular condyle. The inflected angle of the jaw, *a*, characteristic of the *Marsupialia*, is so abrupt in *Thylacoleo* that only the tip is visible in an outer view (fig. 1, *a*), and this, with the angle, hardly rises above the level of the lower border of the ramus. In the Potoroo and Koala (ib., fig. 3) the angle (*a*) is relatively larger, rises higher, is less directly inflected, and the whole comes into the outer view of the ramus, as in other Marsupial Phytophagans (see fig. 4, *Phalangista;* also the Paper of 1871, p. 260, fig. 16, *Dendrolagus*, and fig. 18, *Bettongia*).

---

[*] 'Memoir on the Megatherium,' 4to., 1860, plate 25, fig. 1, iii.; and 'Memoir on the Mylodon,' 4to., 1840, plates 15 and 17.

[†] The following is CUVIER's description of this phalanx in the Feline family:—"La figure de cette phalange est celle d'un crochet fait des deux parties: l'une dirigée en avant, courbée, tranchante et pointue, reçoit l'ongle, dont la forme est à peu près la même: la base de cette première portion fait une espèce de capuchon osseux, dans lequel est reçue la base de l'ongle comme dans une gaîne." 'Leçons d'Anatomie comparée,' 8vo., ed. 1835, tome i, p. 434: "*Les dernières phalanges dans la famille des Chats.*" It is equally applicable to the subjects of figures 6 and 8 in Plate 40.

[‡] "On the Affinities and probable Habits of the extinct Australian Marsupial, *Thylacoleo carnifex*, OWEN," Quarterly Journal of the Geological Society of London, March, 1868, vol. xxiv., p. 307.

In the vegetarian Diprotodonts the ascending ramus of the jaw supporting the articular condyle, *c*, and coronoid process, *b*, is relatively narrower and loftier than in the sarcophagous kinds. (Compare fig. 3 (*Phascolarctos*) and fig. 4 (*Phalangista Cookii*) with figs. 1 and 2, Plate 41.) The latter, indeed, comes nearer than *Phascolarctos*, in retaining the small, seemingly, functionless denticles between *p* 4 and *i* 1.

But the crucial test is the shape and relative position of the articular condyle, *c*. In all existing Phytophagans it rises above the level of the molar series, in most considerably, as in the figures cited: in the existing carnivorous Marsupials, as *Thylacinus* (*loc. cit.*, p. 235, fig. 11) and *Dasyurus* (ib. ib., fig. 12) it does not rise above that level. In the shape of the condyle, the transverse much exceeding the antero-posterior diameter of its convex articular surface, and in its sessile attachment forbidding predication of a neck, carnivorous characters are seen in *Thylacoleo* which are wanting in all Marsupial Phytophagans. In all the characters in which the mandible of the Marsupial Lion agrees with that of the smaller pouched Carnivores, the resemblance is still closer to that bone in the type Carnivores of the placental series.

In the Paper of 1871 I was unable to oppose Professor FLOWER's conjectural restoration of the mandible of *Thylacoleo* (*loc. cit.*, p. 307), according to the type of that bone in the Koala and Potoroo by other than a conjectural restoration (ib. ib., fig. 8; and Plate 12, fig. 1) in which the inferred relative position of the mandibular condyle is indicated by the curved line, *b*, in the text. The two restorations may now be tested by the figures from nature in Plate 41.

DESCRIPTION OF THE PLATES.

PLATE 39.

Fig. 1. Palatal or working surface of the teeth of the upper jaw, *Thylacoleo carnifex.*

Fig. 2. Corresponding surface of the teeth of the lower jaw, ibid.

Both figures are of the natural size.

PLATE 40.

Fig. 1. Radius, *Thylacoleo carnifex.*

Fig. 2. Proximal articular surface of the same bone.

Fig. 3. Proximal end of ditto.

Fig. 4. Ulna, *Thylacoleo carnifex.*

Fig. 5. Front view of proximal articular surface.

Fig. 6. Ungual phalanx, *Thylacoleo carnifex.*

Fig. 7. Under view of ditto.

Fig. 8. Claw-bearing portion, with one-half of the sheath removed.

(In ungual phalanges, probably of the hind jaw, the sheath is little, if at all, developed.)

PLATE 41.

Fig. 1. Outside view of mandible and teeth, *Thylacoleo carnifex.*

Fig. 2. Inside view of mandible and teeth, *Thylacoleo carnifex.*

Fig. 3. Outside view of mandible and teeth, with grinding surface of the molars, *Phascolarctos fuscus.*

Fig. 4. Inside view of mandibular ramus and teeth, *Phylangista Cookii.*

Fig. 5. Outside view of mandible and teeth, *Plagiaulax Becclesii.*

All the figures are of the natural size.

XVI. *On the Morphology and the Development of the Perithecium of* Meliola, *a Genus of Tropical Epiphyllous Fungi.*

By H. Marshall Ward, *B.A., Fellow of Owens College, Victoria University; late Cryptogamist to the Ceylon Government.*

Communicated by W. T. Thiselton Dyer, *C.M.G., M.A., Assistant Director, Royal Gardens Kew.*

Received November 28,—Read December 14, 1882.

[Plates 42–44.]

During the course of recent researches into the nature of parasitic fungi, my attention was arrested for some time by several forms of epiphytal growths which occupy a sort of half-way position between the more pronounced endophyllous parasites, and those fungi which cannot be looked upon as requiring more than a hold-fast or shelter from their hosts. Among these are the *Meliolas*, a group established by Fries in 1825 to receive certain tropical fungi.* In the 'Annales des Sciences Naturelles' for 1851† is a memoir by Bornet on the species constituting the genus *Meliola*, in which the characters of these remarkable epiphytes are enumerated and examined, and a classification of the known forms proposed: this paper is a standing authority on the subject, and I shall have occasion to refer to it at intervals subsequently, partly to confirm some of Bornet's work, partly to add new observations and correct older views as to the nature or significance of various points.

The *Meliolas* are minute epiphyllous fungi, belonging to the *Pyrenomycetes*, the deep-brown or black mycelium of which appears as sooty patches on many and various plants in the tropics, and presents, roughly, a similar appearance to the masses of *Capnodium* or *Fumago* sometimes observed in European woods on the leaves of living plants.

Though, according to Bornet, several species must have been known under different names to the earlier botanists, the name established by Fries, and published in his revised system, was accepted by Montague and Léveillé and has persisted since: Berkeley, in England, has referred to the group in his 'Cryptogamic Botany,' and has described several species from the tropics in various papers.

---

* 'Systema Orbis Vegetabilium.'

† Ser. iii., Bot., t. xvi., pp. 257, &c.

The habit of these fungi, and the fact that no true *Erysiphe* had been found among the collections of travellers in the tropics, led FRIES[*] to insist strongly on the known or supposed analogies between the two genera, and, BORNET following FRIES, the *Meliolas* have thus come to be regarded as replacing the *Erysiphes* in tropical countries—as, in fact, "representative species." BORNET added several facts to those already known concerning the coarser anatomy of the group; but even his excellent and systematic memoir left large gaps in the knowledge of important details, and practically nothing was known of their development or of the formation of their "fruit-bodies." These and other gaps I hope to fill up to at least a large extent in the present essay.

The appearance of this fungus as presented to the unaided eye, is much the same as that offered by *Asterina* and similar forms, and the reader may be referred to a recently published drawing of that fungus for a tolerably accurate idea of it.[†] The chief difference is that the black maculæ presented by well developed plants of *Meliola* are more decided and thicker than those of *Asterina;* all transitions are found, however, and, as with many other forms of epiphyllous *Pyrenomycetes*, it is impossible to detect exactly what fungus is present by a superficial examination.

The fungus *Meliola* may be conveniently considered as composed of a mycelium, which supports appendages and perithecia, and which arises from spores developed within the asci of the latter. BORNET considered the "receptacle" as an equally important and distinct constituent, but this is perhaps unnecessary since, as will be shown, the so-called "receptacle" can only be looked upon as a more or less accidental development, so to speak, depending and following upon the formation of the perithecium.

The mycelium, forming the chief part of the black patches found on the surface of the affected leaves, petioles &c., spreads in an irregularly stellate manner from a common centre or centres (see Plate 42, fig. 1). It is detached with comparative ease from the epidermis of the leaf, and bristles with fine, simple or branched, pointed appendages, of a black colour, which spring from the main hyphæ, and from around the subglobular perithecia which are irregularly scattered over the surface.

The main hyphæ constituting this vegetative part of the fungus, are irregularly radiating, sinuous or zigzag filaments, closely appressed to the epidermis of the leaf, &c., and composed of cylindrical joints or cells placed end to end, and branching at angles of about 45 degrees (*cf.* Plate 42, fig. 2, and Plate 43, fig. 5). Their stiff and even brittle walls are deeply coloured brown or black, and thus obscure the view of their contents: sections and reagents prove these to be finely grained protoplasm, with or without oily drops in the interior. The diameter of the hypha is equal throughout, the apex being, as a rule, evenly rounded: the cross-septa dividing the hyphæ into cells are firmly marked, thick, and dark-coloured like the outer walls.

---

[*] 'Sumna Vegetabilium,' p. 406: "Genus in foliis tropicis vulgatissimum ut *Erysiphes* in terris temperatis."

[†] Quar. Journ. Micr. Sc., October, 1882, plate 27, figs. 1 and 2. See also BORNET's beautiful figures, Ann. des. Sc. Nat., ser. iii., t. xvi., plates 21 and 22.

The main branches of the mycelium all present the same general characters described above. In many cases, however, the blunt apices of the larger hyphæ, instead of being evenly rounded, become curiously deformed by an accumulation of abnormal growths, of the nature of caps (see Plate 43, fig. 7) fitting roughly one over the other: these consist of swollen, more or less cuticularised thickenings of the cell-wall, with or without granular débris between the layers. They are evidently produced by irregularities in the forward growth of the hypha: in the moist intervals the growing apex, more delicate than the older portions of the hypha, creeps along the surface of the leaf in the normal manner; during recurrent dry and hot unfavourable periods, however, sudden hardening and stoppage of growth causes the accumulation of the caps. That unfavourable intervals in outward circumstances may produce such abnormalities is well seen in the *Saprolegniæ*, and I have in these observed the formation of successive shell-like caps of dense cellulose, more or less altered, and enclosing granular matter between the layers: the caps are coloured blue by solution of zinc-chloride and iodine, the granular débris yellow. These phenomena were by no means uncommon with the hyphæ of *Achlya* and *Saprolegnia* grown, in summer, too long in the same water; of course the pathological changes are produced by different causes in the two cases.*

Besides the main branches of the mycelium, certain small pyriform or flask-shaped outgrowths are given off at pretty regular intervals from the cylindrical cells of the larger hyphæ (see Plate 42, fig. 2, and Plate 43, figs. 3 and 4): in some cases each cell or joint gives off such a short branchlet from each side, in others from alternate sides. More rarely they are absent altogether. In all cases examined the short lateral branchlet arises as a simple bulging out of the lateral wall of the cell: as this proceeds, the bud (as it may be considered) swells out, and its cavity finally becomes separated from that of the parent branch by a firm septum. The long axis of the bud-like protuberance is very generally, though not always directed at an angle of nearly 45 degrees with that of the portion of the main hypha lying nearer the growing point (see Plate 42, fig. 2, &c.): its walls are similarly dark coloured and firm, and it contains fine grained protoplasm much as the cells of the main hyphæ. Morphologically considered, the short lateral outgrowths are undoubtedly of the nature of arrested branches.

In one form of *Meliola*, growing on the leaves of a species of Convolvulus, I have observed a second form of the lateral branchlet (see Plate 43, fig. 4), co-existing with the commoner pyriform type. In this case the outgrowth was longer, narrowed into a sort of neck, and presented the general shape of a Florence flask, seated with its bulged out body on the parent branch. In some specimens, each cell of the latter supported two opposite flask-shaped branchlets: in others only one, with or without a pyriform body in addition. Sometimes one or the other type occurred singly and irregularly (fig. 4).

---

* There seems reason to believe that further investigation may throw light on this subject in connexion with the apposition of the cell-wall.

The flask-shaped body is sometimes open at the apex, though I have never succeeded in observing anything emitted from the pore. These flask-shaped appendages recall to mind the peculiar bodies figured by WORONIN in another group of the *Pyrenomycetes* (*Sordaria*),* and although no grounds exist for correlating the two phenomena in detail, the fact is at least worth recording that the lateral pyriform bodies in *Meliola* are capable of subserving reproduction, as will be shown hereafter.

When the hyphæ or branchlets of this fungus are looked upon from above, and a strong light passes through from below, one often observes a minute, circular, bright spot, which appears to shine through the upper wall like a very small oil-drop; on reversing the object, so that the lower side of the hypha comes uppermost, this brilliant pore-like spot appears much more evident, and is clearly due to a thinning in the wall of the under side of the hypha, at a spot where no colouring matter is deposited in the cell-walls, and where the contained protoplasm is placed more nearly in connexion with the outside (see Plate 43, fig. 7, and Plate 44, figs. 21, 40).

BORNET apparently refers to these bright spots when he speaks of oily globules in the interior of the hyphæ,† though he may have been speaking of actual oil-drops developed in the dried specimens with which he chiefly worked. If BORNET's remarks refer to the bright spots here described, the facts of their appearing only on the lower wall, and not being altered by alcohol, &c., remain to be explained.

Taking all the facts into account, the view seems to recommend itself that these bright spots are the points of attachment of the hyphæ to the epidermis; if so, they are to be regarded as *haustoria* of a very rudimentary nature. The mycelium certainly is attached to the surface of the leaf, though but feebly, and it appears suggestive that alcohol specimens are more easily detached than fresh ones, possibly because the protoplasm becomes contracted and rendered brittle. No other anchoring bodies have been observed, and one notes that the position of these brilliant spots accords with that of the well-developed *haustoria* in *Asterina*,‡ a genus of fungi at least allied to the *Meliolas*. These bright points are not always present, and in some cases seem to be normally absent. They are very generally formed at once on germination, appearing on the first short tubes put forth by the spore (fig. 40), a condition of things which may again be compared to what occurs in *Asterina*,§ and also in *Erysiphe* and allied forms.‖ Still another point reminding us of *Asterina* and the *Erysipheæ* is the function of the pyriform branchlets; in some cases at least, they become detached, and act as vegetative reproductive organs or *conidia*, each putting forth bud-like processes which develop into new hyphæ. Bornet remarked the separation of these buds in *Meliola amphitricha*, and hints at their possibly serving as reproductive bodies much as the *Oidium* forms of *Erysipheæ:* since he worked with dried specimens, however, this question could not be decided.

---

* "Beiträge zur Morph. u. Phys. d. Pilze," DE BARY and WORONIN, ser. iii., plate 5.

† *Op. cit.*, p. 260, and plate 21, fig. 3.

‡ See my description in Quar. Journ. Micr. Sc., October, 1882.

§ BORNET, *op. cit.*, plate 28, fig. 5.

‖ DE BARY, "Beiträge zur Morph. u. Phys. d. Pilze," 1870, R. iii., plate 12, figs. 1 and 2.

Bornet remarks that the mycelium on the upper side of many leaves are sterile, while those below and protected from the direct rays of the sun alone support *perithecia:* this is certainly not true for the species examined by me, and, indeed, I cannot determine any difference between the upper and lower mycelia in this respect. Those on the upper surface seem quite as productive of spores, &c., as those below, and in many cases—*e.g.*, those *Meliolæ* so common on *Memecylon*—the mycelium vegetates almost exclusively on the upper surface, and is quite fertile there.

Besides the short pyriform and flask-shaped branchlets described above, the mycelium bears certain stiff, upright appendages of the nature of *setæ* (see Plate 42, figs. 1, 41, and Plate 43, fig. 8): these *setæ* spring from the cells of the hyphæ at various points in their course, and, from their position and mode of origin, are probably to be regarded, morphologically speaking, as lateral branchlets which become elongated in a direction more or less perpendicular to the plane of the leaf. Such a *seta* grows very rapidly and soon reaches its limit: the cylindrical cells composing it are relatively longer than those of the hyphæ, but resemble them in other respects (the walls being, perhaps, somewhat stiffer and more deeply coloured) and taper above, in the simple types, or become variously branched.

In most *Meliolas* the *setæ* are especially aggregated around the perithecia, forming circles of stiff radii springing from what Bornet terms the "receptacle": they are also developed, however, from various isolated points of the mycelium bearing no direct relation to the fruit-bodies.

The forms of the *setæ* vary from a simple, upright or curved filament, to structures branched like antlers, trifurcate, twisted, &c., at the tip (*cf.* Plate 43, fig. 8 and Bornet's figures*): Bornet has made use of these details in classifying the formal species, and although it is doubtful whether the more similar types are constant, there can be no objection to their use much in the same manner as the appendages of *Erysipheæ*, &c., are used to distinguish the forms of that group. Bornet regards the origin of the *setæ* at points on the mycelium as marking out places where new *perithecia* are to be developed: I cannot say that this idea is altogether a false one, but investigation of the development of the fruit-bodies seems to show that at least no necessary connexion exists between the two phenomena.

As to the function of the *setæ*, little or nothing can be stated. The earlier suggestions of Sprengel and Fries (as quoted by Bornet) that they may be organs for the exit of the spores cannot be accepted: not only on the ground of the disproportion between the numbers, but also because the spores are too large to pass through the *setæ*, even supposing the cavity continuous and ending in an ostiolum, which is not in the case. I have often tried to discover *conidia* or other bodies in connexion with the *setæ*, but have been forced to the belief that they have no function whatever connected with spore-production. One is not now impressed with the necessity for assigning any special function to such structures: if the *setæ* are merely free-growing branches of the otherwise appressed, creeping mycelium, there is nothing surprising in the fact that some differences in form and consistency are correlated with their sub-äerial habit. This is at least no more remarkable than that the looser branches of an alga, like *Coleochæte*, should have a facies slightly differing from that of the cell series comprising the lower, creeping, appressed parts of the thallus.

---

* *Loc. cit.*, plates 21 and 22, figs. 6, 15, 16, &c.

The collection of *setæ* immediately around the "fruit-body" simply results, immediately, from the vigorous development of hyphæ which accompanies the later stages of formation of the perithecium: this mass of setigerous hyphæ, which seems comparable with the formation of *haustoria* and such-like organs in other fungi during the fruit development, was called the "*réceptacle*" by BORNET. As to a possible protective influence of the circles of *setæ*, the question must be left open until we know more of the conditions: in some cases, at any rate, the *setæ* do not arise until the perithecium is completely formed, and the spores nearly ripe.

The perithecium, when completely developed, is a globular or sub-globular body, consisting of a shining black or brown external case, the outer thick walls of which appear regularly embossed, and an internal mass composed of asci and spores, &c. The embossed pattern on the outer walls results from the thick-walled cells, of which it is composed, projecting at their free surfaces: where the cells join each other forming polygonal figures they do not so project.* What may be termed the base of the perithecium is sessile on the mycelium: at the opposite pole, or apex, is frequently a slight papilla, not obviously pierced by any pore. BORNET, noting this fact, imagines that the dehiscence takes place below, the whole upper part of the perithecium becoming broken away by a circular rupture at the base. In some forms, at least, the spores escape through an opening at the apex: how far this is general I do not know (Plate 42, fig. 43), but facts exist to render it probable that a minute and dilatable pore occurs in others.

Vertical sections of the mature perithecium show that within the firm, deep-coloured, external wall is a lining of softer cells, with swollen envelopes and of a more or less flattened form: this inner lining of the perithecium extends two or three cell-series deep, and is slightly yellow or pale-brown in colour (see Plate 44, fig. 33, and Plate 42, fig. 34). In the cavity thus enclosed are the groups of asci in various stages of development: these delicate, clavate sacs contain spores, or have emptied them into the semi-gelatinous, granular matrix around. With these preliminaries, I may pass on to consider and describe the development of the perithecium, as followed step by step on a species of *Meliola* which I have investigated with no slight success:* this will be found to throw light on the morphology of these fungi from the best of sources—development—and aid in a more critical estimation of their proposed systematic position. After describing in detail the origin, mode of development and fate of the fruit and spores, I propose, therefore, to examine the relations of the *Meliolas* to *Erysiphe* and other fungi.

---

* See BORNET's figures, *loc. cit.*, plates 21 and 22.

On examining portions of the epiphyllous mycelium bearing the short, pyriform, lateral branchlets so often referred to above, one frequently discovers specimens presenting the appearances depicted at figs. 9, 10, 11, &c. The simple pyriform body, after becoming more swollen, has suffered division into two portions or cells by a septum, usually vertical to the plane of the mycelium and leaf, and passing diagonally across the cavity with a slight curve, so as to abut on the outer walls at right angles, or nearly so. The originally unicellular protuberance becomes in this manner divided into two more or less unequal cells, and it will be shown in the sequel that these two cells have, from the first, each a different destiny in the formation of the fruit. For this reason I have indicated in the drawings, by shading, a difference which does not present itself in the natural object at this stage. The more apical cell, which is smaller and shaded darker in fig. 9 (Plate 42), may be indicated throughout by the letter A: it will be found that this cell produces the central ascogenous tissue of the young perithecium, while the other (which will be referred to as cell B) originates the outer portions of the case or perithecium wall.

Following close upon the preliminary division above described, a septum appears across the larger of the two cells, cutting the first-formed division wall at right angles, or nearly so: this is rapidly followed by another septum (Plate 43, fig. 10), and so the larger cell (B) becomes cut up into three. Following upon these, a number of further divisions in planes at right angles to the preceding are soon established (figs. 11 to 17), and at the same time, though much more slowly, one or two more division walls are formed in the cell A, thus cutting it up into a short series of about three cells (figs. 14, 15).

If the above description has been followed, it becomes clear that the division of the more rapidly growing cell, B, results in the production of a sheet of cells affixed, so to speak, to the few-celled mass resulting from the slow division of A: such being the case, and the sheet extending as new divisions are formed, the cells resulting from A become gradually enveloped more and more in those resulting from B. A comparison of the figs. 9 to 17 will facilitate matters here, and for convenience of description hereafter, and in consideration of its destiny, we may term the mass of cells produced from A the "*ascogenous core*"—or simply the core.

At a stage which may conveniently be considered the next one to fig. 11, the cells resulting from the division of B are observed to be extending as a curved layer over the "core" of cells formed by A. If, at this stage, the young fruit-body is cut off, and allowed to roll over in fluid under the microscope, the form and arrangement are found to be somewhat as sketched in fig. 12 (Plate 43), where *a* represents the view from below, *b* that from the side, and *c* an end elevation of the structure. The cell A, in fact, is becoming gradually enfolded by the layer of cells derived from B, a process which results, at a later period (Plate 43, fig. 17) in the almost complete tucking in of the "core" as the centre of a subglobular mass of cells.

---

* I must take this opportunity of thanking Professor De Bary for kind suggestions with respect to this work.

As this process of "invagination by epiboly" (as it would be termed in the case of an embryo) goes on, the "core" has been more slowly cut up into cells—at first by walls perpendicular to its long axis, and then by septa in other planes at right angles —and the sub-globular body thus produced lies with the open part towards the epidermis.

After this period, two events occur: 1st, the cells of the "core," possessing very thin walls, acquire a different aspect from those of the outer shell; their finely granular protoplasm makes them appear denser and more opaque, shining through the latter until this becomes too thick to be transparent; 2nd, the open part of the growing perithecium becomes closed over, and the internal structures can no longer be made out without the aid of actual sections. At this point my observations have failed to decide which of two possible modes of growth take place: Is the covering in of the "core" completed simply by the extension and closing in of the edges of the outer layer; or are cells, cut off from the "core" below, intercalated, so to speak, into the open gap? One is led to expect by analogy that the former process takes place, but some events lead to the suspicion that such may not be the case.

At the stage corresponding to fig. 19 (Plate 43), the young perithecium appears almost opaque, very little light passing through the dark-coloured and thick outer walls; from below, however, the larger cells composing the "core" can be readily seen in the optical section, shining by means of their dense, fine-grained contents through the shell. In the next stages, the "core" can only be seen dimly through the outer envelope (Plate 44, fig. 20), even after treatment with reagents, or, as in figs. 21 and 22, after cutting or tearing off some of the outer cells.

Nothing but a fortunate vertical section through the young fruit at or near this stage will decide finally whether the lower side is covered in by the meeting of the outer shell edges, or by partial "delamination" from the lower side of the "core," and this I have not succeeded in obtaining. The thick, dark outer walls have now become so opaque, that optical sections fail to determine the course of events; and treatment with reagents does not afford evidence sufficiently satisfactory to decide the questions, since it seems impossible to remove the colouring matter. Potassic hydrate or weak acids do, it is true, render the structures a little more translucent after some time; but even the extreme resort of heating in weak chromic acid has only yielded partial results, and with this slight information on the point I have reluctantly been compelled to content myself for the present. A comparison of figs. 17 to 21 certainly suggests that the process of envelopment is completed by the outer layer of cells derived from the repeated and rapid division of the cell B, and this view may be recommended on the ground of analogies with the *Erysipheæ*, to be examined hereafter; but, while figs. 19 and 20 by no means decide the point, we shall find that in the perithecium of another species of *Meliola* (or an allied form) the construction almost certainly proceeds by continued cutting up and "delamination" of the results of division of one cell.

Be this as it may, the young perithecium now consists of the following parts:— A central "core" of delicate-walled, colourless or yellowish cells, very rich in finely granular protoplasm, and, surrounding this completely, a single layer of cells with thick, hard, dark-coloured walls (especially those on the exterior surface); the whole mass is attached to the hypha from which it originated by a very short pedicle or joint (see Plates 43, 44, figs. 19–24).

At a period slightly later than the above, the cells of the outer layer are becoming multiplied by tangential walls, and those of the inner core by radial and horizontal divisions: these processes go on for some time, until the whole perithecium is a complex of many small cells, the outer of which become firmer and darker-coloured, the inner delicate and full of fine-grained protoplasm as described.

No trace of the internal structure is, however, visible now from the outside. On isolating a perithecium at this stage—a matter of no slight difficulty, but practicable with a slender knife used under a low power of the microscope—it presents the forms shown in fig. 25 (Plate 44), on being rolled over. Above, the outer surface curves equally away from the centre, and the slightly projecting walls of the cells give it an appearance of being embossed (fig. 25, *x*.). From below (fig. 25, *y*), the object looks very different; the surface is much flattened and nearly circular, and from many of the cells are processes developing as hyphæ in all directions. These radiating processes creep close along the surface of the leaf, to which the fruit-body is also appressed, and no doubt serve to give a much firmer hold for the fruit; at first their thin walls are only of a pale brown hue, but rapidly acquire the thickness and deep colour of the fruit and mycelium. Seen from the side, the young perithecium presents the appearance sketched at fig. 25, *z*. It is these radiating anchoring hyphæ which form collectively what BORNET terms the "réceptacle," and from them, at a later period, the bristling *setæ* found around the mature fruit are developed.

From the stage just described the development of the fruit-body proceeds rapidly; but, since the objects now become of a more manageable size, I have been able, by actual sections through the perithecium embedded in spermaceti or gum, or, better still, in elder pith, to obtain some insight into the processes going on even in the centre of the mass of cells.

At stages just prior to the one last described, the central core of thin walled cells—which it will be remembered has been derived from continuous divisions of the cell A —is commencing to divide up by septa in several directions (figs. 23, 24), while the outer layers surrounding this—derived primitively from B, and, possibly, in part from

A—are divided more regularly by tangential walls, followed by radial ones at right angles as the area enlarges. As the increasing small and delicate cells of the core become formed more rapidly, a certain tendency at least to a regular arrangement can be recognised in the later stages, as shown in such sections as figs. 28 and 29, (Plate 44), and fig. 27 (Plate 42): this regularity becomes interfered with by the mutual pressure of the cells, and the outer ones, of which the walls are especially soft and swollen, become flattened and pulled in the tangential direction, and only marked by the very granular yellowish protoplasm in their diminishing cavities. In the central lower part of the core, vertical sections at this, and slightly later stages, show that certain cells, with very delicate outlines and finely granular refractive contents, maintain their larger size and upright arrangement, and are by these peculiarities well distinguished as a special group or tuft of cells (see Plate 44, fig. 28 and Plate 42, fig. 31). In oblique (Plate 44, fig. 29) and horizontal (fig. 30) sections passing through the lower third of the developing perithecium, they can also be readily distinguished by their special peculiarities, and no question can be entertained as to their significance in the formation of the essential parts of the fruit-body. This group of cells is the forerunner of the young asci, and may be termed the *Ascogonium.*

As development proceeds continuously, the outermost layers acquiring thicker and more deeply coloured walls, the above named group of upright cells become relatively larger, increasing slowly in number by a few divisions, while the diffluent, compressed cells between them and the outermost layers slowly give up their contents, and become reduced to mere granular streaks embedded in a jelly-like mass of swollen and fused cell-walls (see Plate 42, fig. 31). This process is exactly comparable to what takes place in the developing embryo-sac of certain phanerogams,* or of the pollen mother cells in the anther,† in so far as the larger cells clearly develop at the expense of material derived from those around.

The tuft of successful cells thus nourished is, in fact, the "ascogonium" of this fungus. At a slightly later stage than the one last figured, the space formerly occupied by the deliquescent remains of small cells is filled with an almost transparent semi-fluid mucus, in which a few bright granules are embedded; while the lower part of the perithecium contains a tuft of asci in various stages of development (see Plate 44, fig. 33), and which have evidently proceeded from the large cells of figs. 28 and 31 (Plates 44 and 42), which have devoured all, or nearly all, the smaller soft cells surrounding them.

Sections of perithecia at a stage between those shown in figs. 31 and 33 (Plates 42 and 44) have not been obtained, but enough evidence has been secured to enable me to conclude that the asci are the direct result of the transformation of the elongated upright cells of fig. 31 (Plate 42), which are nourished at the expense of the cells of the inner layers. Partly from the brittle nature of the outer walls, enclosing a space filled with almost fluid contents, and partly from the extreme delicacy of the young asci, I have been unable to decide whether any distinct branching of the ascogenous cells precedes the formation of the definite asci: probably such is the case. We have now followed the development of the perithecium to the period when it may be considered ripe: a period of some duration, since the asci are continually and successively formed in the tuft for some time.

---

* *Cf.*, amongst others, STRASBURGER, 'Angiospermer und Gymnospermen.'

† *Cf.* STRASBURGER, 'Bau und Wachsthum der Zell-haute,' 1882.

Fortunate sections of the perithecium wall at this stage have yielded the following information. In the centre of the apical wall, where a slight protuberance sometimes occurs, the cells of the inner wall are found to radiate towards a pale translucent spot or pore (see Plate 42, fig. 36), and although I have not been able to obtain sections exactly through this, and am therefore unable to affirm positively that it is an actual pore, there seems little doubt that this is at least the weak point through which the spores escape from the ripe perithecium, no doubt forced through by the swelling of the materials around. BORNET* believes that the perithecium opens by a circular rupture at the base: I have tried to confirm this, but failed, and am strongly persuaded that the apical spot figured is the point of exit for the spores. That a minute pore should escape observation from without is not remarkable: the reflection of the light from the black shining outer cells might easily obscure it. The general structure of these walls has already been described, and fig. 34, drawn from an extremely fortunate and very thin section, shows the details.

The very young ascus presents no features of importance to distinguish it from that of many other pyrenomycetous fungi. In its earliest state it is recognisable as a single thin-walled, club-shaped cell, tapering to a point at the lower attached end, and filled with finely granular, yellowish protoplasm (see Plate 44, fig. 37, *a.*): sometimes a small pale, refractive nucleus-like point is seen in the protoplasm. As the young ascus grows longer, and its protoplasm increases in quantity, a fine, sharp division line makes its appearance somewhat oblique to the long axis of the whole (fig. 37, *c.*); this is soon followed by a second, similar longitudinal division, in a plane at right angles to the former (fig. 37, *d.*), and four well-defined masses are thus marked out. These, the young spores, do not include the whole of the protoplasm (fig. 37, *d.* and *f.*), but lie in a scanty matrix of granular matter, closely opposed face to face, and following the curve of the enlarging ascus wall on their outer walls.

As the four, almost fusiform young spores increase in size, and acquire more distinct membranous envelopes, they come to lie somewhat more loosely in the cavity of the ascus, and may cross one another in accommodation to the space at disposal. Then appear cross-septa (fig. 37, *e.*, *f.*), dividing the material of the spore into a number of compartments varying from three to five—or, in one case, a single septum only is formed—and vacuoles and granules appear in the hitherto almost homogeneous contents. As the spores ripen, their cross-septa become more firmly marked, their outer walls thicker, and, gradually brown or nearly black in colour, like the hyphæ of the developed mycelium; the side walls of the separate compartments also become bulged out slightly, giving the mature spore the appearance of a long oval body, constricted at intervals (see Plate 42, fig. 39). Very commonly one or two oily-looking drops accumulate in the compartments of the ripe spore.

---

* *Op. cit.*, p. 261.

Such is the typical mode of development of the perithecium, asci and spores. I have found no modifications of importance from a morphological point of view; it should be recorded, however, that the number of spores in the ascus varies from two to eight. Sometimes in the same perithecium one finds asci in which one, two, or three spores develop at the expense of their presumably weaker neighbours (fig. 38), in other cases the number two appears constant, only one complete division occurs in the ascus (fig. 38), while in one case to be referred to later, the asci normally produce eight two-chambered spores (Plate 42, fig. 43).

On germination, which may take place soon after their emission from the ripe perithecium, the spores seem to behave generally in the same manner; one or several simple protuberances emerge from any of the partitioned chambers (see Plate 42, fig. 40), and proceed to develop into a typical mycelium, often with a preliminary formation of the rudimentary haustoria referred to in an earlier part of this paper. This mycelium grows rapidly in moist weather, forming branches, *setæ* and fruit-bodies as before. In some seasons the leaves of various plants may be seen covered with hundreds of these young mycelia, which dry up when the atmosphere does, only to renew their growth with the rains.

Before passing on to the consideration of the pathological influence of these fungi, and of their systematic position, I will record a few details concerning a form of *Meliola* which varies somewhat from the typical cases hitherto considered; at any rate, it seems to differ more from the six or eight forms to which the above description refers, than they do among themselves.

The species to be examined has only been found on the leaves of *Pavetta indica*, and its mycelium forms more spreading and less defined patches on the leaves of that plant, than the easily recognisable sooty patches of the other *Meliolas*. The main features of its mycelium, &c., are shown in fig. 41, and differ chiefly in the delicate straggling hyphæ, with a paler brown colour and no trace of haustoria. The branching is very irregular, and somewhat like that of the form figured at fig. 3, but the short, lateral branchlets are not always ovoid, but often have sinuous, almost angular outlines, reminding one of the similar structures in *Asterina*, except that the latter bear distinct haustoria. The *setæ* are here quite simple, short, and not so hard and brittle as usual; they are also produced in smaller numbers than in the more typical species.

The greatest peculiarities, however, are offered by the fruit-bodies, or perithecia. Each of these arises as before by the successive dividing up of a short, lateral branchlet (Plate 44, fig. 42), with this difference, that the rapidly following septa permit no recognition of primitive cells destined to form the outer walls, ascogonium, &c., as before.

After a few radial, vertical, and horizontal walls have been formed, tangential septa (fig. 42, *d.*) make their appearance cutting out series of cells which are to form the outer walls, and which become firmer and more deeply coloured, from an inner cell mass which gives rise to the ascogonium much as before. Only a few asci are formed, in each of which arise eight small oval uniseptate spores, which acquire a pale brown colour as they ripen (fig. 42, *f.*, and Plate 42, fig. 43).

The mature perithecium is shaped like a pear or top, the broad end attached to the hypha by a short pedicel, the narrow free end, or apex, becoming thin and diffluent in order to allow of the escape of the spores (fig. 43). Very few or no *setæ* are formed around the perithecium, and these of the same simple type as those scattered on the mycelium (Plate 42, fig. 41). The whole structure of the fruit-body is, therefore, much simpler than that of the above described forms, and, from the semi-translucent characters of the thinner cell-walls, allows the main details to be made out by optical sections only. In some of the dark-coloured cells of freshly prepared specimens, a bluish tint is often observable; I have not seen this in any other similar form.

In no case have I succeeded in tracing a distinct alterative or destructive action of the *Meliolas* on the cells of leaves to which they are attached. In many instances, as, for example, thick leathery leaves like those of *Memecylon capitellatum*, &c., the haustoria seem to have no function beyond that of holdfasts; in others, such as *Pavetta*, *Triumfetta*, &c., attacked leaves certainly suffer from the presence of the fungus. Nevertheless, I cannot trace this to any direct action of the mycelium; the contents of the cells show no effects which can be regarded as due to the fungus mycelium directly. We must conclude, therefore, that where the life of the leaf is interfered with at all, it is indirectly; the dense crust of a well-developed *Meliola* no doubt obstructs the play of physiological functions in an obvious manner, by obscuring it from light, blocking up stomata, &c.

It is now possible to consider the question of the systematic position of these remarkable and interesting fungi. BORNET,[*] following FRIES and LÉVEILLÉ, places *Meliola* near the old group of *Sphaerias*, with especial reference to *Erysiphe*. I have already quoted the view of FRIES that the *Meliolas* may be considered tropical representatives of our *Erysipheæ*, and BERKELEY[†] takes the same position. These opinions appear to have been based simply on the resemblance in habit and the more obvious anatomical characters, and on the fact that no *Erysiphe* is known in the tropics.

The detail of structure, and especially of the development of the fruit-bodies above described, enable us to criticise these views from a somewhat firmer standpoint.

Apart from minor points of resemblance between *Meliola* and the typical *Erysipheæ*, such as the haustoria (not well developed in *Meliola*), the asci, &c., there can be no question as to certain points of agreement in the structure and development of the perithecia; nevertheless, the origin of the fruit-body in the two groups is not obviously similar, and at first sight the differences may seem greater than they really are.

[*] *Op. cit.*, p. 266.

[†] Introd. to 'Crypt. Bot.,' p. 275.

In the typical simpler *Erysipheæ*, such as *Podosphaera*, as is well known from DE BARY's classical researches,[*] the "*carpogonium*" and "*antheridium*" arise each as a short lateral branch from separate hyphæ, at the point where two hyphæ cross: each becomes cut off by a septum, which is formed close to the parent hypha in the case of the pyriform "*carpogonium*," and about half way up the curved "*antheridium*" branch. The free end of the latter becomes closely applied to the top of the *carpogonium*, and fertilisation—possibly not complete in a physiological sense, however—is said to be complete. After this process numerous branchlets arise from the base of the *antheridium* filament (and also from the base of the *carpogonium*), grow rapidly and with numerous segments, and invest the *carpogonium*, which meanwhile begins to be (more slowly) cut up into cells.

In *Eurotium*[†] we have an essentially similar process, except in minute details, and the *antheridium* is a branch springing from the same hypha which bears the *carpogonium*, and arises just beneath the latter. Here, as before, the perithecium envelope is formed chiefly by the rapid overgrowth of cells derived from the *antheridium* branch. It is quite conceivable that a form allied to *Erysiphe* and *Eurotium*, &c., might have the unicellular *carpogonium* and *antheridium* arising quite in contact at their bases from the same branch.

If we now compare the above with the succession of events in the development of *Meliola*, the following points of analogy seem to me sound. The original pyriform branchlet—containing in itself, so to speak, the elements of the fruit-body—after the first division (Plate 42, fig. 9), may be considered as establishing morphologically an "*archecarpium*"[‡] and an *antheridial branch*—or the latter may be considered as containing in itself the *antheridium*, *plus* the elements of the perithecium wall.

If the cells A and B (fig. 9) became further developed, and diverged at their apices, we should have no difficulty in seeing these points of homology.

Thus much cannot but be allowed. The cell A resembles a true *archecarpium* in so far that it slowly produces the ascogonium and asci; the homology will not be weakened, but the contrary, if further research shows that part of the perithecium wall results from cells derived from A. The cell B so far acts as an *antheridium* branch in that it is closely applied to A, divides up more rapidly, and thus produces most—*perhaps all*—of the perithecium wall.

The above may possibly suggest some difficulties to those who have not followed the recent progress in our knowledge of sexual organs and their homologies in the lower fungi. It has of late been shown to be not improbable, but on the contrary very likely, that we should view the *Erysipheæ* as a group connecting the higher *Ascomy-*

---

[*] "Beitr. z. Morph. u. Phys. d. Pilze," R. iii., 1870.

[†] *Cf.* DE BARY, *loc. cit.*

[‡] DE BARY, Beiträge IV., proposes to use this word as denoting that part of the body which becomes the ascus and pedicel in *Podosphaera*.

cetes, on the one hand, and the *Phycomycetes*[*] (*Mucor*, *Peronosporeæ* and *Saprolegniæ*) on the other: the evolution of the latter group seems undoubtedly attended by a fusion of parts before separated—a withdrawal of the sexual organs, so to speak, into one another,—and DE BARY has followed this out with marvellous skill and success in a number of forms passing from *Pythium*, through the *Peronosporeæ*, to certain *Saprolegniæ*, in which the male sexual organ ("*antheridium*," "*pollinodium*,") is normally suppressed. Whether or not we suppose, with DE BARY, that the *Erysipheæ* took origin from some *Peronospora*-like form, it seems reasonable to look upon *Meliola* and its immediate allies as a branch group derived from the *Erysiphe* stem, either from the ancestor of *Erysiphe* itself or from ancestors which gave rise to *Eurotium* and *Erysiphe*, and that this group has become developed in tropical lands along lines more or less parallel to those along which the European forms have proceeded in temperate climates, being, in fact—though not in the strictest sense perhaps—"representative species." Be this view entertained or rejected, I am strongly impressed with the necessity for further and closer investigation of the very remarkable group of fungi centering around or near the *Meliolæ*, since they will probably fill up yet more completely the gap—partially bridged over, it is true—between the lower and higher *Ascomycetes*.

DESCRIPTION OF PLATES.

Fig. 1. *Meliola* sp. with portion of epidermis of *Memecylon*. On the mycelium are *setæ*, branchlets, and fruit-bodies in various stages of development.—ZEISS D.

Fig. 2. Mycelium of another species of the same, found on the leaves of *Schutereia* (*Conv.*), with portion more highly magnified.—GUNDL. $\frac{1}{8}$ and ZEISS D.

Fig. 3. Portion of mycelium of a species of *Meliola* on *Triumfetta* (*Tiliaceæ*).—ZEISS D.

Fig. 4. Portions of more advanced mycelium of fig. 2 more highly magnified, and showing various forms of lateral branchlets.—ZEISS J.

Fig. 5. Portions of mycelium on *Memecylon* showing mode of branching and young fruit-bodies.—GUNDL. $\frac{1}{8}$ and ZEISS D.

Fig. 6. Vertical section through portion of mycelium where fruit-body is being formed. The section is not median.—ZEISS J.

Fig. 7. End of hypha with three cap-like thickenings and pore-like spot (*haustorium* ?) seen from below.—ZEISS J.

Fig. 8. Various forms of *setæ* in plan and elevation.—ZEISS D and J.

---

[*] *Vide* DE BARY, "Beitr. z. Morph. u. Phys. de Pilze," R. IV., 1881.

Fig. 9. End of hypha (with one cap-like thickening) bearing lateral pyriform branchlet which is to become a Perithecium. The first oblique septum has already appeared, the smaller cell (A) represents the ascogonium, &c., and is shaded darker; the larger one (B) will divide up more rapidly, and enclose the cell A and its progeny.

Figs. 10 and 11. Further stages in the development of the young Perithecium. The cell B is becoming divided.—Zeiss J.

Fig. 12. Young Perithecium seen from below (*a.*), from the side (*b.*), and from one end (*c*). In all, the dark cell is the one marked (A) in fig. 9; the remainder have resulted from the growth and division of the cell (B.)—Zeiss J.

Figs. 13 and 14. Slightly later stages seen from below. The cell (A) has become divided by a cross septum.—Zeiss J.

Figs. 15 and 16. Similar preparations seen from above and below.—Zeiss J.

Fig. 17. Somewhat more advanced Perithecium seen from the side. The cells resulting from the division of A ("ascogenous core") are seen through those formed by B, which are growing over them.—Zeiss J.

Fig. 18. Somewhat more advanced stage.—Zeiss J.

Fig. 19. Slightly later stage. The upper figure is seen from above, the lower from below: the latter shows the "ascogenous core."—Zeiss J.

Fig. 20. Similar preparations seen from above (lower figure) and below (upper figure.) —Zeiss J.

Figs. 21 and 22. Slightly advanced Perithecia cut by the razor. The "ascogenousc ore" is exposed at the cut parts.—Zeiss E.

Figs. 23 and 24. Similar preparations treated with chromic acid. The "ascogenous core" is seen enveloped by the cells forming the Perithecium-wall: all much swollen, and fig. 23 slightly crushed.—Zeiss J.

Fig. 25.—More advanced Perithecium seen from outside and above (*x.*), below (*y.*), and from the side (*z.*). The radiating hyphæ (réceptacle) spring from the external walls below.—Zeiss E.

Fig. 26. Portion of mycelium with young Perithecium seen from above and below.—Zeiss E.

Fig. 27. Somewhat older Perithecium. The razor has cut off one side obliquely. —Zeiss J. (camera).

Fig. 28. Vertical section through young Perithecium about this stage. The ascogenous cells in the middle are distinguished by their larger size and arrangement. —Zeiss J.

Fig. 29. Oblique (nearly horizontal and median) section through the same.—Zeiss J.

Fig. 30. Horizontal section above the base of same.—Zeiss J.

Fig. 31. Somewhat older stage in vertical section. The ascogenous cells in the centre are enlarging at the expense of those around.—Zeiss J.

Fig. 32. Portion of outer wall with disorganised cells lining it.—Zeiss J.

Fig. 33. Vertical section through nearly ripe Perithecium, showing asci and spores embedded in the gelatinous mass produced by the disorganisation of the unemployed cells.—Zeiss D.

Fig. 34. Portion of outer wall of latter in vertical section.—Zeiss J.

Fig. 35. Vertical—not median—section through ripe Perithecium (and portion of epidermis of host-plant), showing crowds of spores.

Fig. 36. Thin slice from top of similar Perithecium. A pore-like spot is seen in the centre of the radical marking.

Figs. 37, 38 and 39. Various stages in the development of the asci and spores.—Zeiss J.

Fig. 40. Germinating spores.—Zeiss D. and E.

Fig. 41. Portion of mycelium of a species of *Meliola* found on *Pavetta*, showing mycelium, *setæ*, and young Perithecia.—Zeiss J. and D.

Figs. 42 and 43. Development of Perithecia and extrusion of spores.

XVII. *On the Atomic Weight of Glucinum* (*Beryllium*).

By T. S. Humpidge, *Ph.D., B.Sc.*

Communicated by Professor E. Frankland, *F.R.S.*

Received March 20—Read April 12, 1883.

[Plate 45.]

I. *Introductory.*

Ever since the discovery of glucinum by **Vauquelin**, in 1798, its atomic weight has been a disputed matter amongst chemists. Its discoverer considered that its oxide was a monoide, an opinion which was however strongly opposed by **Berzelius**, who wrote the oxide Gl_2O_3 and the atomic weight 13·7 (O=16). The researches of **Awdejew*** and **Debray**† again turned the scale in favour of the earlier view, and as an atomic weight of 9·2 suited the properties of the metal in the tables of periodicy constructed by MM. **Mendeleef** and **Lothar Meyer**, this atomic weight has, up to quite recently, been generally accepted by chemists. As a welcome confirmation to this came a determination of the specific heat of the metal by Professor E. **Reynolds**,‡ who found that for its atomic heat to be near the normal number 6·0, its atomic weight must be 9·2 and not 13·8. Almost immediately afterwards a second determination of the specific heat was made by MM. **Nilson** and **Petterson**,§ who, however, obtained a result agreeing not with the lower atomic weight but with the higher.

The reasons for these conflicting opinions are to be found—first, in the anomalous position of glucinum among the elements; secondly, in the difficulties which surround the preparation of even small quantities of the free metal in a tolerably pure condition; and thirdly, in the fact that no volatile compound of glucinum is known of which the vapour density might be easily determined.

The constitution of the compounds of glucinum cannot be inferred from any physical or chemical similarities with analogous compounds of other metals. Its compounds most closely resemble those of magnesium and aluminium, but also differ from these in the most striking manner. None are isomorphous with any similar compounds of these two metals, if we except the result of **Ebelmen**,[*] who is said to have obtained the oxide isomorphous with alumina. The volatility of its chloride, its tendency to form basic compounds, its stable double fluorides with potassium and sodium, as well as the solubility of its hydrate in caustic soda or potash, all point to analogy with aluminium; while its carbonates, its double sulphate with potassium, and the greater simplicity of some of its double compounds when its oxide is written as a monoxide show similarity with magnesium.

---

* Pogg. Ann., lvi., 101.

† Ann. Chim. and Phys. [3], xliv., 5.

‡ Phil. Mag. [5], iii., 38; Chem. News, xlii., 273.

§ Berl. Ber. xi., 381, 906.

A correct solution of this long-vexed question can therefore be only obtained either from the specific heat of the element or from the vapour density of some of its volatile compounds. Two determinations of the specific heat have been made, as referred to above, but with quite contradictory results; and, as far as I am aware, no determination of the vapour-density of glucinum chloride, nor of its compounds with ethyl and propyl, discovered by **Cahours**, has yet been made. The metal used by Mr. **Reynolds** in his experiments was prepared in a platinum crucible, and was apparently impure. His calorimeter, or as he prefers to call it, *atometer*, was "essentially a spirit thermometer with a test-tube sealed in the bulb." In the absence of any detailed description of his apparatus, and especially of the means adopted for its graduation, it cannot be definitely decided whether accurate results were possible or not. M. **Nilson** used iron vessels to prepare his metal and carefully determined its composition. It contained 13 per cent. of various impurities, which were allowed for in calculating the actual specific heat of the metal. The determinations were made with **Bunsen**'s accurate and delicate ice-calorimeter.

The researches detailed in this paper were undertaken to obtain, if possible, a purer metal than M. **Nilson**'s, and to redetermine its specific heat. The vapour-density of volatile glucinum compounds I hope to refer to in a later paper.

II. *Extraction of glucina.*

Of the various methods recommended for the extraction of the earth from its commonest mineral beryl, I shall here only allude to two. The first consists in decomposing the finely-powdered mineral by fusion with potassium carbonate, disintegration of the fused mass with sulphuric acid, evaporation to dryness, to render the silica insoluble, concentration to separate most of alumina, as alum, and treatment with ammonium carbonate as in the second method. This process, otherwise a good one, is objectionable, because of the high temperature necessary to decompose the mineral, and because the fused mass is only very slowly attacked by the sulphuric acid. I have usually followed a different method, due to **Scheffer**,[†] which consists in decomposing the mineral by hydrofluoric acid. Briefly, the process is as follows:—The finely-powdered mineral is mixed with excess of powdered fluor spar and sulphuric acid

[*] Ann. d. Ch. u. Pharm., lxxx., 211.

[†] Jahres. Ber. 1859, 139.

in a large leaden dish, which is furnished with a leaden lid, and is heated on a water-bath for two or three hours. The remaining sulphates are next heated in an iron crucible to expel the excess of acid and any traces of silica, then dissolved in warm water and the calcium sulphate filtered off. To the filtrate, sufficient potassium sulphate is added to form alum with the alumina present, and the solution evaporated down to crystallize. The mother-liquor, from which nearly the whole of the alumina has been thus removed, is then slowly dropped, best by a separating funnel, into a large excess of warm concentrated ammonium carbonate solution, with constant stirring. About ten times as much of the salt is necessary as the quantity of glucina supposed to be present. The whole is then placed in stoppered bottles, and allowed to stand for four or five days, after which no change appears to take place. At the end of this time the solution, which contains nearly the whole of the glucina, some alumina, and often not inconsiderable quantities of iron, is then filtered, and colourless sodium sulphide added as long as ferrous sulphide is thrown down. If the quantity of iron present produces only a coloration, but no precipitate, it is well to add a little ferric chloride, and then completely precipitate with sodium sulphide. This is the only method I know of, except fusion with acid potassium fluoride, which removes every trace of iron. In the filtered solution the ammonium carbonate is now to be decomposed by boiling, but if the concentrated solution is heated directly over the flame very violent bumping cannot be avoided. A better plan is either to dilute freely with water (to about three times the bulk), or else to warm for about two hours over a water-bath, and when most of the ammonium carbonate has been decomposed, then to boil over the flame. The final traces of the carbonate are removed by acidulating with hydrochloric acid, yielding a solution from which ammonia precipitates the hydrate. By repeating the process the glucina is obtained nearly pure. Absolutely pure it can only be prepared from the double potassium fluoride, K_3GlF_6, by fusion with acid potassium fluoride, and recrystallizing the double fluoride from hot water. The quantity of the acid fluoride required by theory (6 : 1) should be used, not only 2 : 1, as recommended by Dr. WOLCOTT GIBBS, who, I believe, first introduced the process. The purified double fluoride is then readily decomposed by the requisite quantity of concentrated sulphuric acid in a platinum dish, and the hydrate precipitated with ammonia in the usual manner.

A very good yield may be obtained from beryl by this hydrofluoric acid process, provided the mineral is sufficiently finely powdered. Fairly pure compounds of glucinum may, however, be now obtained from some continental manufacturing chemists, which only require once purifying with ammonium carbonate for all ordinary purposes.

III. *Separation of metallic glucinum.*

Metallic glucinum may be obtained either from its double fluoride with potassium or from its chloride, of which the latter is decidedly the most suitable compound.

The double fluoride, K_3GlF_6, melts at a low red-heat without decomposition.

In the fused state it readily conducts an electric current with the formation of metallic glucinum at the negative pole. The metal so obtained is, however, largely contaminated with impurities derived from the vessel in which the experiment is conducted, which is strongly attacked by the free fluorine. In one experiment with platinum electrodes—the positive electrode being a platinum crucible in which the salt was fused—the crucible lost two decigrammes in weight. The double fluoride may also be decomposed by fusion with sodium or potassium, but in this case also only a very impure product results, owing to corrosion of the vessels employed. It is possible that by using an *iron* crucible a purer metal might be obtained.

The metal used in the determination of its specific heat was prepared from its chloride, which compound was obtained in the usual way by heating a mixture of the oxide and sugar charcoal in dry chlorine. I have found it better to employ starch paste (made of pure wheaten-starch) in place of the oil which is commonly recommended for mixing the oxide and charcoal. If starch paste is used a much more compact mass is obtained after the subsequent glowing in charcoal powder, but which is still sufficiently porous to allow the chlorine to penetrate into the interior. It is advisable to employ a hard glazed porcelain tube for heating the mixture in the stream of chlorine, this being far less attacked by the chloride than hard glass. Absolute purity of the oxide used to prepare the chloride is not necessary, as, owing to the high temperature at which glucinum chloride condenses, any traces of aluminium or silicon which may be present are carried, with traces of the chloride, to the less heated portions. If, however, iron is present, it is not completely removed.

Glucinum chloride melts at about 600° (CARNELLY) to a brown liquid, of which the electric resistance is so great that it is apparently not decomposed even by a powerful current. On connecting the wires from a battery of forty quart BUNSEN cells in series with platinum electrodes dipping in fused glucinum chloride and with a galvanometer, no deflection of the needle of the instrument was observed. I can therefore confirm NILSON'S result that the chloride is practically a non-conductor of electricity. The fused or gaseous chloride is readily decomposed by sodium, but if vessels of platinum, porcelain, or glass are used the metal obtained is largely contaminated with impurities derived from the vessels. To overcome this difficulty DEBRAY* used lime. He constructed boats of a mixture of lime and alumina, placed sodium in the first and the chloride in the second, then introduced them into a tube of hard glass through which was passed a stream of dry hydrogen. The boat containing the sodium was first heated, then that containing the chloride, so that its vapour was carried by the stream of hydrogen over the fused sodium. The metallic glucinum so obtained was a compact, fibrous, crystalline mass, and was probably purer than any prepared in platinum vessels. NILSON and PETTERSON first proposed iron vessels for the reduction of the chloride. They heated equivalent quantities of the chloride and sodium in a massive iron cylinder and thus obtained a metal resembling DEBRAY'S, and comparatively pure.

---

* *Loc. cit.*

I first attempted DEBRAY'S method, but owing to the difficulty of procuring compact boats of lime or of a mixture of lime and alumina of sufficient size, no good results were obtained. Nor did I get good results with NILSON'S process. I found considerable difficulty in excluding the oxygen of the air; the tubes could scarcely be unscrewed again when cold, as the sodium chloride had solidified in the thread, and when opened it was not easy to extract the metal without contamination from the outside scale. A modification of the two methods was therefore adopted, which answers admirably.

Iron boats were constructed of pieces of tubing partly filed away, and with end pieces screwed on. They were about 200 millims. long and 20 millims. in diameter. In order to prevent any contact of the reduced metal with the glass of the tubes, the boats were enclosed in slightly longer pieces of entire iron tubing, and in these cases were introduced into a wide tube of hard glass. As in DEBRAY'S method, the first boat contained about the requisite quantity of sodium, the second the glucinum chloride. When the tube had been filled with dry hydrogen, the boat containing the sodium was heated until the metal was fused, the heating was then continued backwards to the chloride, the vapour of which thus passed, mixed with the excess of hydrogen, over the molten sodium. After the somewhat violent reaction had ceased and the tube was again cold, the boat containing the reduced glucinum, together with the sodium chloride produced and the excess of sodium, was placed in a vessel of crude alcohol until hydrogen ceased to come off. It was then removed to water to dissolve out the sodium chloride. Compact crystalline masses of glucinum were thus obtained, always, however, mixed with more or less basic chloride and oxide, even when the experiment was most carefully conducted. The larger pieces of metal could be easily removed from the liquid and purified by washing with cold dilute caustic soda, which dissolves out any oxide, but is without action on the metal. The residue was then likewise treated with caustic soda, and preserved separately as being less pure. The iron boats and tubes were not attacked during the reaction, except that blisters were raised on the outer tubes which, unlike the boats themselves, were of steel. The metal was of a steel-grey colour not so white as aluminium, but considerably harder, and can be beaten into thin sheets under the hammer. Compressed in a steel mortar it yielded a compact disc of metal—0·7 gramme thus treated gave a disc 15 millims. in diameter and 3 millims. thick. Its specific gravity at 10° C. was found to be 1·84, or making allowance for the impurities present, 1·70. As it was suspected that the metal so compressed might still contain air, it was first boiled for half an hour in water before determining its specific gravity. All attempts to fuse the metal were without any good result. It remained apparently unaltered when heated to bright redness in the air, and probably became covered with a thin coating of the oxide. Heated under sodium chloride in a lime crucible by the oxyhydrogen flame imperfect fusion was obtained. When similarly heated and exposed to the air it burnt with a dazzling, bluish light. The metal dissolved readily in dilute acids leaving a minute trace of insoluble matter, quite imponderable. When 3 centigrammes were dissolved, the residue could not have been as much as 0·1 milligramme. To determine the amount of iron contained in it, 0·0341 gramme was dissolved in dilute sulphuric acid in a stream of carbonic acid, and then required 1·4 cc. of a potassium permanganate solution of which 1 cc. was equivalent to 0·32 milligramme iron, which gives the percentage of iron present to be 1·32. The oxide mixed with the metal was found by dissolving 0·0340 gramme of the metal in dilute hydrochloric and precipitating the hydrate with ammonia and weighing, after thorough washing, as oxide. The amount taken gave 0·0883 gramme oxide, corresponding to a percentage of 4·71. The composition of my metal was therefore :—

Gl . . . . = 93·97
Gl_2O_3 . . . . = 4·71
Fe . . . . = 1·32
SiO_2 . . . . = traces
100·00

That obtained by M. Nilson, the only other sample which has been analysed, had the composition :—

Gl . . . . = 87·09
Gl_2O_3 . . . . = 9·84
Fe . . . . = 2·08
SiO_2 . . . . = 0·99
100·00

I believe it is possible by using purer chloride to obtain a metal almost chemically pure by the method described above.

The position of glucinum in the electro-chemical series is a peculiar one, and deserves passing notice. In dilute acids (hydrochloric, nitric or sulphuric) glucinum is strongly electro-negative to magnesium, and feebly positive to aluminium. In caustic potash or caustic soda, the series is different, and glucinum is now negative to both metals, feebly to magnesium, strongly to aluminium; while in ammonium carbonate the series is the same as for dilute acids. These results may be thus tabulated:—

(i.) Dilute acids and ammonium carbonate.

+Mg, Gl, Al−

(ii.) Caustic alkalies.

+Al, Mg, Gl−

IV. *Determination of specific heat.*

The most accurate method for determining the specific heat of substances of which small quantities only are available is undoubtedly that devised by **Bunsen**, in which, as is well known, the quantity of ice at 0° which is melted by a given weight of the substance heated to a high temperature is measured by the diminished volume which the water produced occupies. Unless, however, the whole apparatus is kept exactly at the freezing-point, accurate results are not possible, and even under the most favourable conditions there is usually a mean error of nearly one per cent. **Bunsen** originally immersed his instrument in a large box of pure freshly-fallen snow to preserve it accurately at 0°—a proceeding which has been somewhat simplified by **Schuller** and **Wartha**, who coat the exterior vessel with a thick layer of ice, and work in ice-cold water. But even with this modification it is scarcely possible to use the apparatus in England, and especially on the west coast, where frost in the winter is the exception rather than the rule.

Several kinds of rough calorimeters based on the same principle have been proposed in which the heated substance produces an expansion in a liquid at a definite temperature. Among these are the *atometer* of Mr. **Reynolds**, which was used to determine the specific heat of his glucinum, and a similar form described by Professor **Balfour Stewart**.* No instrument of this description can, however, give accurate results unless most carefully shielded from external sources of heat and carefully calibrated, especially when a liquid expanding so irregularly as alcohol is used. As far as can be judged by the published results, no calibration has been attempted, and therefore the results obtained cannot be of much value.

A very simple form of apparatus has been devised by **Kopp**† who places the substances in a glass tube with naphtha, and heats in a bath of mercury. Considerable dexterity must be requisite to remove the heated substance from the bath of mercury to the calorimeter in exactly equal times, and a further objection is the small range of temperature through which the substances can be heated. His results, too, do not agree so closely with one another as those obtained by **Bunsen's** or **Regnault's** methods, especially when only small quantities are used.

To overcome these various objections a modification of **Regnault's** method of mixtures has been adopted, which with small quantities of the substances (0·7 to 7 grammes) gives results with a mean error of one per cent. or less, and which can be easily worked by one person without assistance. The errors in **Regnault's** apparatus have been pointed out by **Neumann** and **Pape**.‡ They showed how a cooling effect must be produced by an upward current of cold air when the heating arrangement was opened at the top, and explained that, in many cases, the water equivalent of the casing of brass wire gauze used to contain the substances was greater than that of the substances themselves. As far as possible these errors have been avoided in the following modification of REGNAULT's method. The apparatus consists of two parts—that for raising the substance to a high temperature, and the calorimeter proper.

---

* Proceed. of the Phys. Soc., iv., 52, 342.

† Phil. Trans., 1865, 71.

‡ Pogg. Ann., cxx., 337, 579.

The *heater* is an annular brass vessel of 32 millims. internal and 64 millims. external diameter, and is 115 millims. high (Plate 45, fig. A.). Its lid screws on firmly and is made steam-tight by indiarubber packing, freed from sulphur by previous boiling in caustic soda. Three tubes pass through the lid of the heater, the central one carrying a thermometer (T_1), which gives the temperature of the interior air bath, while the other two enclose platinum wires connected with the arrangement for supporting the substance and for allowing it to fall into the calorimeter at the correct instant. All connexions in the lid are made as air-tight as possible to prevent any upward current of cold air into the heater. The substance is supported in a small platinum capsule (B) attached by a hinge to one of the platinum wires referred to above, and this capsule is held in a horizontal position by the second platinum wire, the end of which is bent at right angles to its length. To the upper end of this platinum wire is fixed a strip of wood, so that the wire can be easily turned through a small angle, the catch released, and the substance allowed to fall into the calorimeter. The heater is completely covered by a double coating of thick baize, and is placed in a wooden box (not shown in the figure). In the bottom of this wooden box is a small slider (C) which is connected with an electro-magnet and can be opened or closed at will. Two tubes (D, D) connect the annular space of the heater with a boiler containing water, placed on the other side of a tin screen, and with the air. The whole heating arrangement stands on a larger box (E) open at one side and with a long base board, and this again is supported on a suitable wooden stand.

The *calorimeter* itself (F) is a small thin platinum vessel of 50 millims. in diameter and 60 millims. in height, and containing therefore when full about 100 cc. It is furnished with an agitator of two discs of thin perforated platinum, soldered with gold to two thin platinum wires, one of which terminates about 15 millims. below the lid of the brass casing in a hook. To this hook a silken string (G) is attached, which passes over pulleys and is kept stretched by a small weight. The two discs of the agitator have perforations at one side for the bent thermometer (T_2), which gives the temperature of any liquid contained in the calorimeter. The advantages of using platinum for calorimeters have been pointed out by BERTHELOT. It always remains bright and of constant weight, and from its low specific heat corresponds to a very small equivalent of water. The weight of my calorimeter and agitator is 74·40 grammes, and its water equivalent 2·41 grammes, but it might have been made very much thinner. The calorimeter stands on three boxwood cones in a brass casing, which is fixed by three pieces of cork to a sliding board. This brass casing is 85 millims. high and 77 millims. in diameter, and its movable lid is furnished with a small slider which can be opened or closed by two iron armatures working in the two solenoids (H and H) placed one on each side. The wires from those solenoids terminate in four points of German silver at the end of the board (only one of which, J, is shown in the figure), which when the calorimeter is drawn up into its place under the heater come into contact with four springs of the same metal (K) connected with the battery and a switch. The board on which the calorimeter and its appurtenances are fixed can be moved by strings from the position shown in the figure to that exactly under the heater and back again.*

To obtain accurate readings of the different temperatures, two standard thermometers were first constructed, with a millimeter scale, and calibrated by GAY-LUSSAC'S method, using Mr. F. D. BROWN'S excellent little instrument.† These two read between about 5° and 105° C., and 1 millim. is about equivalent to 0°·2 C. They were compared with one another for every half degree between 8° and 20° C., in a large bucket of water, kept suitably agitated, and in only one instance differed by more than 0°·02 from one another. The bent thermometer (T_2) was more open, and 1 millim. was about equal to 0°·1 C. It was very carefully compared, by two series of experiments, with the two standard thermometers together, and the mean temperature taken when they differed from one another. The thermometer T_1, used for the heater, read accurately to 0°·05 C., was corrected for the boiling point, but not calibrated; the correction for the exposed thread was determined experimentally, and was found to be 0°·03 less than given by the usual formula :—

$$C=m\,(T-t)\,n.$$

The water-equivalent of the thermometer T_2 was calculated, from the weight of mercury which it contained, and the weight of glass immersed, to be 0·5 gramme, which agreed with experimental results.

Readings of the temperature to which the substance was heated are thus correct to at least 0°·1 C., and of the calorimeter to 0°·01 C.

The liquid used in the calorimeter is French turpentine, purified and redistilled. Taking the specific heat of this liquid as 0·4, and its specific gravity as 0·87, about 28 small calories are requisite to raise the temperature of 80cc. through one degree, and only a small weight of the substance is required. Thus, for silver, the quantity necessary would be $\frac{28}{80\times0\cdot057}=6$ grammes (circâ), and for aluminium $\frac{28}{80\times0\cdot2}=1\cdot7$ gramme (circâ) for a fall in temperature of 80°: much smaller weights than are required for any other accurate method, except BUNSEN'S. With a temperature difference of 1°·00, and reading to 0°·01, the mean error cannot well be smaller than 1 per cent., and with the instrument in its present form, this is, in fact, the limit of error. More accurate results might be possible with a still smaller calorimeter, and a still more open thermometer.

One possible objection to the use of turpentine was loss by evaporation during the experiment; this, however, was found to be too small to affect the results to any appreciable extent. The loss between two experiments, even after removing the substance, never exceeded 0·1 gramme, and a difference of 0·05 gramme would only produce a much smaller error than a difference of 0°·01 in reading the bent thermometer. In order to still further test the evaporation, the calorimeter was left open, exposed to the air of a warm room for 16 hours, and then only lost 0·26 gramme. Provided, therefore, that the agitator or substance does not rise above the level of the liquid, the loss by evaporation during an experiment can be very safely neglected.

---

* A battery-power of four quart BUNSEN or GROVES' cells is necessary. More convenient than this is a bichromate battery so arranged that the zincs can be lowered into the liquid when required.

† Phil. Mag. [5], xiv., 57.

A series of blank experiments were next made to determine whether the calorimeter gained heat during the time that it was open to receive the substance. It was found that the shortest time possible in which the whole series of operations could be performed—the calorimeter run under the heater, the substance introduced, and the calorimeter returned to its original position—was five seconds, and during this time no change could be noticed in the thermometer T_2. If, therefore, the operations follow one another promptly the gain of heat to the calorimeter may be safely said to be within the unavoidable errors of reading. All readings were of course made through a telescope.*

The following is the course usually adopted in the experiments. The substance, weighed to milligrammes, is introduced into the heater from below, this part of the apparatus being removed from its stand for the purpose. The heater is then returned to its position, the wooden slider adjusted, and the two tubes connected with the boiler and waste pipe respectively. During the time that the substance is heating, about 70 grammes of turpentine are poured into the calorimeter and weighed to centigrammes. The calorimeter is then placed in its brass casing, the string attached to the agitator, the thermometer and electro-magnets adjusted, and then a large plate of glass placed in front of the whole apparatus. At the end of about an hour's *vigorous* boiling the thermometer in the heater becomes stationary, starting with all cold, or in about three-quarters of an hour if the instrument has been previously used. This maximum temperature is either higher or lower than the boiling-point, according to the size of the waste pipe. In the experiments already made the waste pipe was generally small and the maximum temperature slightly higher than the boiling-point. Longer heating appears unnecessary, owing probably to the small quantities used. As soon as thermometer T_1 is constant, continuous readings of it and the other thermometer (T_2) are made at regular intervals of one minute. Thermometer T_1 will be quite constant, and if the liquid in the calorimeter is at a temperature within 1° of that of the air, the other thermometer (T_2) should not oscillate through more than 0°·01 in five minutes. At the end of a given minute T_2 is read for the last time, giving the initial temperature of the calorimeter (t), while T_1, giving the temperature to which the substance was heated (T), has been read just before. The substance is now introduced, the calorimeter returned to its original position, the agitator worked a few times and a reading made at the end of the half minute. Renewed agitations and readings are then made for every half minute until the maximum temperature (θ) is reached. The time to reach this maximum for metallic substances, with which I have as yet only experimented, is about a half to one minute.

---

* I should state that in using large weights, as with the 10 grammes of silver, there was sometimes a little splashing, though never exceeding 0·05 gramme.

Although it is not intended to use the calorimeter with water, as the temperature difference would be too small for the small quantities employed, three experiments were made with pure silver, and two with commercial aluminium (re-fused under sodium chloride) to test the apparatus. The following results were obtained, in which T, t and θ have the meanings given above, t' is the temperature of the air, W the weight of water, together with the water equivalent of the calorimeter, agitator and thermometer (2·91 grammes), w the weight of the substance employed, and s the required specific heat.

Silver in water.

I. $W=84{\cdot}25$, $w=10{\cdot}205$, $T=101^\circ{\cdot}9$, $t=11^\circ{\cdot}09$, $\theta=11^\circ{\cdot}71$, $t'=10^\circ{\cdot}9$.

$$s=\frac{W(\theta-t)}{w(T-\theta)}=0{\cdot}05677.$$

II. $W=84{\cdot}03$, $w=10{\cdot}205$, $T=101^\circ{\cdot}9$, $t=11^\circ{\cdot}08$, $\theta=11^\circ{\cdot}69$, $t'=10^\circ{\cdot}7$.

$$s=0{\cdot}05568.$$

III. $W=84{\cdot}01$, $w=10{\cdot}205$, $T=101^\circ{\cdot}9$, $t=10^\circ{\cdot}86$, $\theta=11^\circ{\cdot}47$, $t'=10^\circ{\cdot}4$.

$$s=0{\cdot}05553.$$

Mean specific heat $=0{\cdot}05600$; mean error $=0{\cdot}0003=0{\cdot}6$ per cent.

Aluminium in water.[*]

I. $W=85{\cdot}71$, $w=3{\cdot}502$, $T=98^\circ{\cdot}6$, $t=7^\circ{\cdot}59$, $\theta=8^\circ{\cdot}42$, $t'=8^\circ{\cdot}0$.

$$s=0{\cdot}2253.$$

II. $W=85{\cdot}25$, $w=3{\cdot}502$, $T=98^\circ{\cdot}5$, $t=8^\circ{\cdot}56$, $\theta=9^\circ{\cdot}37$, $t'=8^\circ{\cdot}5$.

$$s=0{\cdot}2212.$$

Mean specific heat $=0{\cdot}2232$; mean error $=0{\cdot}002=1$ per cent.

It will thus be evident that results comparable in accuracy with the best determinations can be obtained with the apparatus, and, I need not add, working entirely without assistance. I intend shortly to make a series of more extended experiments, and if possible to modify the apparatus so that it can be used for higher temperatures than 100°.

---

[*] Using a wider exit tube.

The specific heat of the sample of turpentine was next determined, with results as follows, T, t, θ, and t' having the same significance as before, W being the weight of turpentine used, w the weight of silver, s its specific heat (taken as 0·057), and s' the required specific heat of the turpentine.

Silver in turpentine.

I. $W=75{\cdot}30$, $w=10{\cdot}205$, $T=102^\circ{\cdot}2$, $t=10^\circ{\cdot}98$, $\theta=12^\circ{\cdot}47$, $t'=12^\circ{\cdot}8$.

$$s'=\frac{ws(T-\theta)-2{\cdot}91(\theta-t)}{W(\theta-t)}=0{\cdot}4265.$$

II. $W=75{\cdot}19$, $w=10{\cdot}205$, $T=102^\circ{\cdot}5$, $t=13^\circ{\cdot}32$, $\theta=14^\circ{\cdot}81$, $t'=14^\circ{\cdot}5$.

$$s'=0{\cdot}4165.$$

III. $W=74{\cdot}74$, $w=10{\cdot}205$, $T=102^\circ{\cdot}4$, $t=14^\circ{\cdot}56$, $\theta=16^\circ{\cdot}00$, $t'=15^\circ{\cdot}0$.

$$s'=0{\cdot}4280.$$

Mean specific heat $=0{\cdot}4236$; mean error $=0{\cdot}0044=1$ per cent.

The result obtained by REGNAULT for turpentine at 10° was 0·4278, and by HIRN 0·4241.

Three determinations of the specific heat of the compressed disc of glucinum referred to above were then made, yielding the following closely concordant results, in which the letters have the same significance as before, except that W is the weight of the turpentine and W' its water equivalent + the water equivalent of the calorimeter, &c.

Glucinum in turpentine.

I. $W=72{\cdot}93$, $W'=33{\cdot}77$, $w=0{\cdot}6575$, $T=102^\circ{\cdot}1$, $t=11^\circ{\cdot}09$, $\theta=11^\circ{\cdot}85$, $t'=11^\circ{\cdot}1$.

$$s=\frac{W'(\theta-t)}{w(T-\theta)}=0{\cdot}4326.$$

II. $W=72{\cdot}67$, $W'=33{\cdot}66$, $w=0{\cdot}6568$, $T=102^\circ{\cdot}2$, $t=10^\circ{\cdot}08$, $\theta=10^\circ{\cdot}86$, $t'=9^\circ{\cdot}9$.

$$s=0{\cdot}4264.$$

III. $W=75{\cdot}12$, $W'=34{\cdot}69$, $w=0{\cdot}6565$, $T=102^\circ{\cdot}3$, $t=14^\circ{\cdot}26$, $\theta=14^\circ{\cdot}98$, $t'=14^\circ{\cdot}3$.

$$s=0{\cdot}4357.$$

Mean specific heat of glucinum $=0{\cdot}4316$; mean error $=0{\cdot}0035=0{\cdot}9$ per cent.

Making allowances for the impurities which the metal contained, the true specific heat (s') of the pure metal would be :—

$$s'=\frac{0{\cdot}4316\times100-1{\cdot}32\times0{\cdot}114-4{\cdot}71\times0{\cdot}247}{93{\cdot}97}=0{\cdot}4453,$$

taking the specific heat of iron as 0·114, and that of glucina as 0·247. Multiplying this number by the atomic weight of glucinum when its oxide is a sesquioxide, *i.e.*, 13·65, the atomic heat becomes 6·08, proving conclusively, if DULONG and PETIT's law is true for this metal as it is for all others, that this is the true atomic weight, and not two-thirds of this number, or 9·1.

The specific heat, as above determined, is considerably higher than that found by NILSON (0·4079), and my results might be too great for two reasons. The compressed metal was somewhat porous, and heat might have been produced by the absorption of the turpentine in its pores, and there might be a further error from hygroscopic water. The former supposition could be only decided by enclosing the metal in some impervious envelope, which has not yet been done; the latter possible error was as far as practicable avoided by drying the glucinum for two hours at 150° before each experiment. But, even supposing the above results to be erroneous to the extent of 10 per cent., it is still certain that the specific heat of the metal is nothing near 0·6, as it ought to be if the atomic weight were 9·1.

The result is unfortunate for the periodic law, and is the first serious rebuff which this useful generalisation of facts has received. Glucinum, with the atomic weight of 9·1, finds its natural position as the first element of the magnesium group; but if its atomic weight is 13·65, it falls between carbon and nitrogen, and entirely contradicts the first principles upon which the tables have been constructed. With an atomic weight of less than 12 it might be easily introduced, and it is possible that when absolutely pure such a result might be obtained. NILSON has recently made some determinations with the sulphate which reduced the atomic weight from the number previously given 13·8 to 13·65, but it does not seem quite certain that his compounds were entirely free from aluminium, which would naturally increase the atomic weight. I hope shortly to re-determine this with the purest material it is possible to obtain.

XVIII. *On the Changes which take place in the Deviations of the Standard Compass in the Iron Armour-plated, Iron, and Composite-built Ships of the Royal Navy, on a considerable change of Magnetic Latitude.*

By Staff Commander E. W. Creak, *R.N.*, *of the Admiralty Compass Department.*

Communicated by Sir Frederick J. O. Evans, *K.C.B.*, *Hydrographer of the Admiralty.*

Received March 1,—Read March 15, 1883.

The period comprised between the years 1855-68 was one of active research into the magnetic character of the armour-plated and other ships of the Royal Navy and the iron ships of the Mercantile Navy.

It will be remembered that the Transactions of the Royal Society are rich in contributions to this important and interesting subject; important in a practical sense to the navigator, and of great interest as a subject of intelligent inquiry.

Among these contributions was a paper read before the Royal Society in March, 1865, "On the Magnetic Character of the Armour-plated ships of the Royal Navy, and on the effect on the compass of particular arrangements of Iron in a ship," by Frederick John Evans, Esq., Staff Commander, R.N., F.R.S., and Archibald Smith, Esq., M.A., F.R.S. This paper contained the earliest published results of the system of observation and analysis of the deviations of the compass in the ships of the Royal Navy, which, established in 1861, has been carried out to the present day.

These results showed the magnetic character of the several ships named, from the time of launching until fully equipped and at sea, and also an analysis of the semicircular deviation of those ships which had made short voyages abroad. But the change of magnetic latitude through which the ships passed was so small, and the alternative of heeling the ships in one latitude so difficult, that the authors of the paper were unable to ascertain any but approximate values of the proportions of hard and soft iron affecting their compasses.

The authors write: "The determination of the proportion of the semicircular deviation, or rather of B, which arises from vertical induction in soft iron, and that which arises from the permanent or sub-permanent magnetism of hard iron, is a matter of great interest. Theoretically it may be determined in two modes, either by observing the deviation in two different magnetic latitudes, or by observing the deviation with the ship upright and heeled over. Unfortunately there is a great want of observations under these circumstances."

During the last fifteen years long voyages into high southern magnetic inclination or dip, have been made in every class of ship in the Royal Navy, except Turret-ships, and according to the established system of the Admiralty Compass Department, the observed deviations of their compasses made in all latitudes have been analysed to obtain the values of their coefficients as shown in Table III. of this paper. From these coefficients, the constants of the hard and soft iron producing semicircular deviation at the Standard Compass positions have been computed.

A knowledge of these Constants not only provides a means of predicting for the particular ship examined the probable changes which will take place in her deviation in all parts of the navigable world, but also the power of doing the same for other ships of the same class.

Such being the case, it is thought that the Royal Society will be interested in receiving a paper treating of these subjects, commencing from the time the ships are fully equipped and ready for sea. The earlier magnetic history of the ships might have been included, but the changes which take place in their fitting, and the numerous iron bodies introduced after launching, render a comparison of the deviations observed at different stages of equipment unsatisfactory.

It is proposed to consider six classes of ships, each of which has been selected for the long range of magnetic latitude over which the ships have sailed :—

1. Iron, armour-plated.
2. Iron cased with wood.
3. Iron troop-ships.
4. Steel* and iron cased with wood.
5. Composite built.
6. Wooden ships with iron beams and vertical bulkheads.

These ships have nearly all been launched upwards of a year previous to the observations about to be discussed, and subjected to the vibration caused by steaming at high rates of speed with powerful engines. They may therefore be considered to have attained a state of magnetic stability.†

At the close of this paper will be found in Table III. a short description of the ships, the direction in which they were built, and the coefficients for each Standard Compass.

It is not intended to repeat the several mathematical formulæ by means of which these coefficients have been computed, as they, together with the methods of making the original observations, were so fully described in the paper on "The Magnetic Character of the Armour-plated ships of the Royal Navy," &c., 1865, to which allusion has already been made.

---

* The vessels have iron frames, and are plated with mild steel, containing ·2 per cent. of carbon.

† See Phil. Trans., 1865, Part I., pp. 279–280.

On comparing the results, however, in that paper with those now brought forward for discussion, a remarkable difference will be observed. In the paper for 1865, the coefficients of the semicircular deviation are those of compasses to which no mechanical correction by permanent magnets had been applied. The corresponding coefficients in the accompanying Table III. have, with the exception of the original values in England, been computed from the deviation of compasses for which a permanent bar magnet, or magnets, has been employed to annul or correct the semicircular deviation.

This correcting magnet has in every case been permanently fixed horizontally in the compass pillar, in the resultant of the magnetic forces producing semicircular deviation, and at a distance found tentatively below the card, after the several horizontal and vertical forces affecting the compass had been ascertained.

It may be asked, whether this application of correcting bar magnets of possible variable magnetic moment does not in itself introduce an element of change in the deviation in addition to those of the ship? It may be answered, with the reasonable confidence induced by fifteen years' trial, that the permanency of the magnetic moment of the magnets employed is considered to be assured.

Thus, in the ships named in the tables, the correction by magnets may be considered as the introduction into them of a permanent magnetic force acting independently on their compasses, and in opposition to the permanent magnetic forces of the ships.

It is now proposed to pass on to the chief object of this paper, which is to show the amount and direction of the changes which take place in the deviations of the standard compasses in six different classes of modern vessels in the Royal Navy, on change of magnetic latitude.

Taking the exact coefficients in Table III. in the order in which they stand we have first:—

The constant deviation.

𝔄.

Some rather large values of this coefficient are found in the tables, but it has been proved that for standard compasses placed in the central fore and aft line of the vessel where the iron is symmetrically placed with respect to that position, little or no real value from magnetic causes has been observed. An error in the bearing of the distant object used for swinging the ship, swinging her too fast, or prism error in the azimuth circle, gives fictitious values of this coefficient, which those in the table are considered to be.

Semicircular deviation.

Coefficient $\mathfrak{B}=\frac{1}{\lambda}\left(c\tan\theta+\frac{P}{H}\right)$ (approximate value in degrees $=$B) is the maximum of semicircular deviation from fore and aft forces;

$\frac{c}{\lambda}\tan\theta$ arises from soft iron;

$\frac{P}{\lambda H}$ from hard iron.

Coefficient $\mathfrak{C}=\frac{1}{\lambda}\left(f\tan\theta+\frac{Q}{H}\right)$ (approximate value in degrees $=$C) is the maximum of semicircular deviation from transverse forces;

$\frac{f}{\lambda}\tan\theta$ arises from soft iron, and is zero if the iron is symmetrically arranged;

$\frac{Q}{\lambda H}$ from hard iron.

For determining P and c separately, when $\mathfrak{B}$ has been determined in two different magnetic latitudes, the foregoing equations are put under the form,

$$\frac{P}{\lambda}+\frac{c}{\lambda}H\tan\theta=\mathfrak{B}H$$

$$\frac{P}{\lambda}+\frac{c}{\lambda}H'\tan\theta'=\mathfrak{B}'H'$$

and similarly for Q and f when $\mathfrak{C}$ has been determined in two different latitudes.

From the values of $\mathfrak{B}$ and $\mathfrak{C}$ in the table, the constants P and c, Q and f, have been calculated by the above formulæ, and the results are given in Table I., which for convenience has been placed at the end of this paper.

The explanation of this table is as follows:—

The quantities found in the columns headed "Original P" and "Original Q" are the constants P and Q, arising from the hard iron of the ship before correction by magnets, and which are mainly dependent for their values and sign upon the direction in which the ship's head lay during building. This direction is given under each ship's name.

In the columns headed "Corrected P" and "Corrected Q" are shown the constants P and Q as altered by the correcting magnets.

The quantities $\frac{c}{\lambda}\tan\theta$ and $\frac{f}{\lambda}\tan\theta$ (with their equivalents expressed in degrees) are the changing parts of the coefficients $\mathfrak{B}$ and $\mathfrak{C}$ respectively, for the South of England, which can only be corrected for all latitudes by vertical soft iron bars.

From the constants c and f in the remaining columns, the changing part of the coefficients 𝔅 and ℭ, arising from vertical induction in soft iron, may be computed whenever the magnetic inclination or dip is known, or can be taken from charts of that element.

Before further investigating the effects of a change of magnetic latitude on the coefficients, the question of how far time affects the constants P and Q requires consideration.

On looking over the values of P and Q, it will be remarked that in some ships a change takes place immediately after leaving England, which appears to be neither due to time nor change of latitude, but to another cause which will hereafter be referred to. Taking the values obtained subsequently at different times in the same geographical position it will be found—

		P.	Change.	Q.	Change.
Bellerophon.—Quebec	1874	−·002	·018	−·008	·005
	1876	−·020		−·008	
Iron Duke.—Hong-Kong	1880	−·208	·015	−·002	·035
	1881	−·193		−·037	
Northampton.—Halifax, N.S.	vi. 1880	+·024	·008	−·037	·020
	x. 1880	+·032		−·057	
Active.—Simon's Bay, C. G. Hope	x. 1874	−·120	·024	−·019	·013
	x. 1876	−·096		−·006	
Raleigh.—Spithead	ix. 1874	+·043	·014	+·026	·025
	vi. 1876	+·057		+·001	
Inconstant—Spithead	viii. 1869	−·023	·021	+·016	·001
	xi. 1871	−·044		+·017	
Himalaya.—Plymouth	vii. 1872	−·030	·009	−·061	·003
	vii. 1874	−·021		−·058	
Himalaya.—Simon's Bay, C. G. Hope	viii. 1872	−·030	·009	−·042	·039
	i. 1875	−·021		−·081	
Albatross.—Sheerness and Plymouth	iii. 1874	−·066	·002	+·015	·007
	x. 1874	−·064		+·022	
Boxer.—Esquimault, V. I.	x. 1869	−·008	·004	−·049	·019
	x. 1874	−·004		−·030	
Encounter.—Simon's Bay, C. G. Hope	iv. 1874	+·002	·050	+·022	·023
	i. 1876	−·048		−·001	

Thus, in the worst case amongst the armour-plated, iron, and composite vessels, P takes a year to alter ·015, and generally two or three years for about half that amount. A change of ·015 in P would make about a degree change in the deviation. This evidently slow change of P by time is important, as should P alter during the ship's sailing over a long range of magnetic latitude, the values of *c*, as found by the above formulæ, are correspondingly untrustworthy.

With regard to the constant Q, although more subject to change by time than P, it is comparatively of less importance, as, with few exceptions, the value of the constant *f*, which depends on the constancy of Q, is, if not zero, so small as to be neglected.

Having accepted as the result of fifteen years' trial that the correcting bar magnets are of constant magnetic moment, it would be reasonable to expect that the constants P and Q should remain unchanged in value, except the small decrease due to time. This is nearly the case, yet there are small fluctuations in them which demand notice.

It is known that if an iron vessel be placed in dock for any length of time in one direction with respect to the magnetic meridian, the values of P, and especially Q, undergo small changes dependent upon that relation. If, in addition, the vessel be subjected at the same time to concussion, from whatever cause, the change is greater. On the return of the vessel to her anchorage, or on proceeding to sea when the direction of her head varies frequently, P and Q return slowly to their original value.

It may therefore be inferred, that although P and Q as shown in the tables are for the most part due to permanent magnetism in the hard iron of the ship, there is a small part which is sub-permanent and subject to alterations from concussion, or the vibratory motion caused in the ship by powerful steam-engines when proceeding in a given direction for several days. On the removal of the cause inducing the change in P and Q they gradually return to their original values.

In the turret ships of the Royal Navy, where the standard compass is necessarily placed on a thin iron superstructure, this temporary dislocation of parts of P and Q, caused by the concussion of firing heavy guns and subsequent gradual recovery, is well known and provided for on board by constant observation for deviation of the compass.

Before considering the constants *c* and *f*, which represent the chief part of the changes which take place in the deviation of the compass on change of magnetic latitude, a few preliminary remarks appear to be necessary.

In "Contributions to Terrestrial Magnetism," No. IX.,* Sir EDWARD SABINE records the result of his investigations as to the effects of a change of magnetic latitude on the deviation of the Standard Compass of some wooden sailing ships of forty years ago. He concluded that their deviations were caused by vertical induction in soft iron, that they did not change directly in proportion to the dip, but there was a lagging behind proceeding from a slowness in the soft iron to part with its induced magnetism. For example, a ship passing quickly from 40° N. to 20° N., dip, would find the deviation due to vertical induction in 20° N., dip, to be that of 30° or 32° N.

In considering how far this theory applies to modern armour-plated and iron vessels, it may help to clear the question to note the rapidity with which horizontal soft iron, when magnetised by the earth's horizontal force, takes up and parts with its induced magnetism, as exemplified in swinging a ship for deviation of the compass.

In this operation—during which the direction of the ship's head passes through a complete circle—the deviation caused by horizontal induction in soft iron attains two maxima in an easterly and two in a westerly direction within an hour and a half.

---

* See Phil. Trans., 1849.

Looking to this result, it hardly seems probable that vertical induction in soft iron should be slower in its action, and require perhaps days for full development.

Among the iron armour-plated ships of the tables we have, in the case of the "Triumph" and "Swiftsure" (two sister ships), experimental evidence that there is no sign of "lagging" in the changing part of their deviation, but that it alters directly as the tangent of the dip for any given position of the ship.

Both vessels, from requirements of the service, have their standard compasses placed unusually far from the stern, in a position 13 feet from the top of an armour-plated transverse bulkhead 5 inches thick. These ships were swung in the course of a few successive months, the observed deviations in each case but one corresponding with the dip at the locality, the values of which were as follows:—

$$\text{Triumph} \ldots \left\{\begin{array}{c}\theta.\\ -44^\circ\\ -34\\ -3\\ +38\end{array}\right\} \text{Range of } \theta\ 82^\circ.$$

$$\text{Swiftsure} \ldots \left\{\begin{array}{c}\theta.\\ +67^\circ\\ +17\\ -11\\ -29\\ -52\end{array}\right\} \text{Range of } \theta\ 119^\circ.$$

To proceed with the constants c and f.

The values of c are very valuable, not only as a means of predicting the probable change of deviation for the particular ships in which they are known, but also for ships of similar construction. As an illustration of the similarity of this constant in certain ships, the following examples are given where sister ships are bracketed:—

	c.
Triumph	+·106
Swiftsure	+·110
Northampton	−·021
Nelson	−·014
Shah	−·005
Raleigh	−·006
Comus	+·034
Cleopatra	+·032
Carysfort*	+·044
Boxer	+·023
Pert	+·026
Firefly	+·005
Wrangler	+·002

---

* The "Carysfort" is a sister ship to "Comus" in every respect, with the exception that the former has no vertical iron shaft through which the screw is raised. In the "Comus" and "Cleopatra" this shaft is 30 feet from the compass.

From the position of the standard compass in the "Northampton" and "Nelson," 83 feet from the stern, a positive value of c might have been expected; but there is a transverse armoured bulkhead, 8 inches thick, the top of which is 30 feet nearer the stern than the compass in each vessel, which is the probable cause of the minus sign for c.

It is a subject for further inquiry as to what extent iron masts contribute to the values of c when the Standard Compass is placed near them. A series of experiments was made near Athens, where the magnetic dip is approximately 53° N., and at Singapore, in 13° S. dip, on board the "Ruby."* The Standard Compass of this ship is placed at 6 feet 9 inches from the iron mizenmast. The results showed that at three different parts of the mast (on a level with the compass, and a few feet above, and below that level) the effects of transient induction were very small, and that the mast acted almost entirely as a permanent magnet.

The remaining constant of the semicircular deviation, f, is one which has hitherto been accepted as zero, from the iron in the transverse section of the ships of the Royal Navy—except turret ships—being considered as placed symmetrically with respect to the Standard Compass.

In the Table I., however, there are five ships for which values of f have been discovered, and one, the "Triumph," in which it reaches an amount which could not be disregarded in a forecast of that vessel's deviation for any given geographical position. From Table I. the following values of f have been collected:—

	f.	$\frac{f}{\lambda}\tan\theta$ in England.
Bellerophon.	$-\cdot005$	$-\cdot012=0°\ 42'$
Triumph.	$-\cdot013$	$-\cdot038=2°\ 10'$
Swiftsure	$+\cdot004$	$+\cdot010=0°\ 35'$
Active	$+\cdot004$	$+\cdot010=0°\ 35'$
Himalaya	$+\cdot006$	$+\cdot015=0°\ 52'$
Comus	$-\cdot004$	$-\cdot010=0°\ 35'$

From the peculiar construction of some of the later types of armour-plated ships the constant f will probably attain higher values than those hitherto experienced.

Quadrantal deviation.

Coefficient $\mathfrak{D}=\frac{a-e}{2\lambda}$ (approximate value in degrees $=$D) is the maximum of quadrantal deviation from soft iron symmetrically placed.

Coefficient $\mathfrak{E}=\frac{d+b}{2\lambda}$ (approximate value in degrees $=$E) is the maximum of quadrantal deviation from soft iron unsymmetrically placed.

---

* These experiments were made by Navigating Lieutenant HENDERSON, R.N., of the "Ruby."

On again referring to the paper "On the Magnetic Character of the Armour-plated Ships, &c.," of 1865, we read at page 275, "D and E do not change with a change of geographical position."

As regards 𝔇 this is fully confirmed by the results in the tables. Time alone appears to cause a gradual change in this coefficient during the first two or three years after launching, after which it remains remarkably permanent.

Coefficient ℭ has no real value in the ships under discussion.

Coefficient λ.

$\lambda = 1 + \frac{a+e}{2}$ is a factor generally less than 1, giving the northern component of the mean directive force of the needle, or "mean force to north."

λ, as might be expected from its close connexion with 𝔇, appears to be affected solely by lapse of time similarly to 𝔇; for example, in the "Malabar" (a sister ship to the "Euphrates" of the tables), a valuable series of observations was made between England and Bombay,* the results of which are here recorded.

			λ.
Malabar.—	Spithead,	17 vi. 67	·861
	Aden,	10 i. 70	·861
	Bombay,	$\frac{11}{13}$ ii. 70	·906
	Suez,	xi. 70	·907
	Spithead,	5 ix. 71	·932
	Spithead,	28 x. 78	·930

Each of the above values of λ is the mean of several observations conducted under favourable circumstances, and the observations, as far as they go, confirm the conclusions drawn from other ships in England. The ship's visit to the heat of the tropics seems to have accelerated the change in λ.

Coefficient μ.

$\mu = 1 + k + \frac{R}{Z}$, in which k represents the vertical force caused by vertical induction in the soft iron of the ship; R the vertical force from the hard iron.

The values of μ contribute largely in many ships to the heeling error. For the purpose of eliminating the values of k from R observations in widely different magnetic latitudes are still required.

---

[*] By Staff Commander J. C. Richards, R.N.

In order to show the relative proportions of hard to soft iron affecting the standard compasses of the ships named in the tables—which are cruisers liable to be sent on long voyages—the values of $\sqrt{P^2+Q^2}$ and $\sqrt{c^2+f^2}$ have been placed together here—

	$\sqrt{P^2+Q^2}$	$\sqrt{c^2+f^2}$
Iron armour-plated ships—		
Bellerophon	·216	·005
Iron Duke	·416	·060
Triumph	·039	·106
Swiftsure	·058	·110
Northampton	·345	·021
Nelson	·287	·024
Iron vessels cased with wood—		
Active	·541	·016
Shah	·173	·005
Raleigh	·282	·006
Inconstant	·238	·039
Iron troop-ships—		
Euphrates	·359	·027
Himalaya	·281	·009
Orontes	·219	·029
Steel and iron ships cased with wood—		
Comus	·238	·034
Carysfort	·263	·044
Cleopatra	·076	·032
Composite vessels—		
Ruby	·500	·027
Gannet	·185	·024
Albatross	·232	·029
Boxer	·196	·023
Pert	·244	·026
Firefly	·332	·005
Wrangler	·375	·002
Wooden ships with iron beams, &c.—		
Encounter	·234	·018
Sapphire	·233	·045

On looking through the above values of $\sqrt{P^2+Q^2}$, it will be noticed that large differences occur in ships of similar construction.

It will be remembered that all iron and composite vessels are large magnets, generally of widely different forms. The values of $\sqrt{P^2+Q^2}$ are, therefore, chiefly dependent upon the position which the standard compass occupies on board these ships, considered as magnets.

Again, each iron body introduced during equipment into that great magnet, the ship, tends to modify in one direction or another its action upon the compass.

Consequently, if the compass be moved from the stern along the central longitudinal line of a ship towards her bow, it will be subjected to the influence of forces varying from those of repulsion or attraction, to zero, and then to those of attraction or repulsion.

For example, the "Iron Duke" and the "Triumph"—although not sister ships—are alike in many points, and built nearly in the same direction.

	$\sqrt{P^2+Q^2}$.	Distance of standard compass from stern.
Iron Duke . . .	·416	81 feet.
Triumph . . .	·033	105 „

It might at first sight be inferred from these results, that the position of the compass in "Triumph" is better than in the "Iron Duke." Keeping in view the object—always much desired—of so placing the compass as to have, when corrected, small changes of deviation on change of magnetic latitude, it will be seen this is not the case.

A reference to the values of $\sqrt{c^2+f^2}$, representing the changing part of the deviation, shows that in the "Iron Duke" the value is $+ \cdot 060$; in the "Triumph" it is $+ \cdot 106$. Thus, the "Triumph's" compass would be improved as regards deviation by moving it further towards the stern and away from the armour-plated bulkhead causing the large value of c, and opposing the increased value of P which would ensue, by a bar magnet.

These considerations tend to show the importance of the long-established regulations with regard to the placing of the standard compass in ships of the Royal Navy, which provide, that the best possible position with regard to surrounding iron shall be selected for it, subject to the interests of the ship as an engine of war.

General Conclusions.

The following general conclusions have especial reference to the Standard Compass positions in those vessels mentioned in the tables, and to all others of similar types.

1. A large proportion of the semicircular deviation is due to permanent magnetism in hard iron.

2. A large proportion of the semicircular deviation may be reduced to zero, or corrected for all magnetic latitudes, by fixing a hard steel bar magnet or magnets in the compass pillar in opposition to and of equal force to the forces producing that deviation.

3. A very small proportion of the semicircular deviation is due to sub-permanent magnetism, which diminishes slowly by lapse of time.

4. The sub-permanent magnetism produces deviation in the same direction as the permanent magnetism in hard iron, except when temporarily disturbed, (1) by the ship's remaining in a constant position with respect to the magnetic meridian for several days, (2) by concussion, (3) or by both combined, when the disturbance is intensified.

5. To ascertain the full value of changes in the sub-permanent magnetism, observations should be taken immediately on removal of the inducing cause.

6. In the usual place of the standard compass the deviation caused by transient vertical induction in soft iron is small, and of the same value (nearly) for ships of similar construction.

7. The preceding conclusions point to the conditions which should govern the selection of a suitable position for the standard compass with regard to surrounding iron in the ship.

TABLE I.—Values of the Constant Parameters P and *c*, Q and *f*, at Standard Compass Positions in Her Majesty's Ships.

Geographical position.	Date of observation.	Original P.	Corrected P.	$\frac{c}{\lambda}\tan\theta$ in England.	*c*.	Original Q.	Corrected Q.	$\frac{f}{\lambda}\tan\theta$ in England.	*f*.
Armour-plated ships.									
BELLEROPHON.—Built S. 51° E. Distance of standard from stern 61 feet, from iron mast 15 feet.									
Spithead . . .	3 xi. 73	+·024	−·004	0	0	+·215	+·025	−·012 = −0° 42′	−·005
Halifax, N.S. .	5 viii. 74	..	+·031	..	..	..	−·002		
Quebec . . .	16 ix. 74	..	−·002	..	..	..	−·003		
Trinidad . . .	1 iii. 76	..	−·020	..	..	..	−·003		
Halifax, N.S. .	21 vi. 76	..	−·020	..	..	..	−·010		
Quebec . . .	24 viii. 76	..	−·020	..	..	..	−·008		
IRON DUKE.—Built S. 39° W. Distance of standard from stern 81 feet, from iron mast 17½ feet.									
Plymouth . . .	20 i. 71	+·407	..	+·158 = +9° 5′	+·060	−·166	..		
„ . . .	16 ix. 71	..	−·019		..	..	+·048		
Gibraltar . . .	x. 71	..	−·047	..	..	..	−·008		
6° N. 96° E. . .	10 xii. 71	..	−·047	..	..	..	+·097		
38° N. 136° E. .	22 viii. 72	..	−·110	..	..	..	+·010		
49° N. 140° E. .	viii. 73	..	−·099	..	..	..	+·028		
30° N. 133½° E. .	27 vii. 74	..	−·123	..	..	..	+·054		
12¾° N. 46° E. .	11 iii. 75	..	−·126	..	..	..	−·016		
Plymouth . . .	27 vii. 75	..	−·136	..	..	..	+·042		
Belfast	5 ix. 76	..	−·138	..	..	..	+·034		
Plymouth . . .	18 vii. 78*	+·402*	−·122†	..	..	−·108	−·022†		
Singapore . . .	xi. 78	..	−·193	..	..	..	+·031		
Yokohama . .	vii. 79	..	−·193	..	..	..	−·021		
Hong Kong . .	28 xii. 80	..	−·208	..	..	..	−·002		
„ . .	31 xii. 81	..	−·193	..	..	..	−·037		
TRIUMPH.—Built S. 45° W. Distance of standard from stern 105 feet, from iron mast 27½ feet.									
Spithead . . .	15 v. 78	−·033	−·289	+·304 = +17°40′	+·106	−·020	+·044	−·038 = −2° 10′	−·013
Equator, 24½° W.	20 vi. 78	..	−·222		..	..	−·012		
23° S. 39° W.. .	1 vii. 78	..	−·214	..	..	..	+·009		
40½° S. 78¾° W. .	7 vii. 78	..	−·194	..	..	..	−·001		
Valparaiso. . .	x. 78	..	−·190	..	..	..	−·007		
9¼° S. 80¾° W. .	7 ii. 79	..	−·209	..	..	..	−·001		
20° N. 157° W. .	4 iv. 79	..	−·195	..	..	..	−·003		
SWIFTSURE.—Built S. 56° W. Distance of standard from stern 107 feet, from iron mast 28¾ feet.									
Plymouth . . .	8 v. 82	−·057	−·233	+·304 = +17°40′	+·110	+·010	−·016	+·010 = 0° 35′	+·004
1° S. 26° W. . .	22 vi. 82	..	−·182		..	..	−·007		
23° S. 43° W. .	5 vii. 82	..	−·227	..	..	..	−·086		
Monte Video . .	23 vii. 82	..	−·236	..	..	..	−·031		
Sandy Point, Magellan Straits .	4 viii. 82	..	−·239	..	..	..	−·016		

* Previous to this date the ship had been under repair at Birkenhead.

† After re-correction by a permanent magnet.

TABLE I.—Values of the Constant Parameters P and c, Q and f, at Standard Compass Positions in Her Majesty's Ships (continued).

Geographical position.	Date of observation.	Original P.	Corrected P.	$\frac{c}{\lambda}\tan\theta$ in England.	c.	Original Q.	Corrected Q.	$\frac{f}{\lambda}\tan\theta$ in England.	f.
Armour-plated ships (continued).									
NORTHAMPTON.—Built S. 6° E. Distance of standard from stern 83 feet, from iron mast 22 feet.									
Sheerness	1 xi. 79	+·345	..	−·060 = −3° 25′	−·021	−·008	−·002		
Spithead	18 xii. 79	..	+·050		..	..	−·002		
27½° N. 62¼° W.	23 i. 80	..	+·060	..	..	..	−·053		
St. Lucia	20 ii. 80	..	+·041	..	..	..	−·073		
Bermuda	8 v. 80	..	+·082	..	..	..	−·090		
Halifax, N.S.	27 vi. 80	..	+·024	..	..	..	−·037		
Rimouski, River St. Lawrence	21 viii. 80	..	+·046	..	..	..	−·046		
Halifax, N.S.	1 x. 80	..	+·032	..	..	..	−·057		
Dominica	22 i. 81	..	+·046	..	..	..	−·004		
NELSON.—Built S. 21° E. Distance of standard from stern 83 feet, from iron mast 23 feet.									
Sheerness	28 vii. 81	+·281	..	−·043 = −2° 30′	−·014	−·060	..		
Plymouth	28 ix. 81	..	+·032		..	..	+·027		
Madeira	11 x. 81	..	+·048	..	..	..	+·016		
Simon's Bay, C. G. Hope	14 xi. 81	..	+·048	..	..	..	+·040		
Iron ships cased with wood.									
ACTIVE.—Built N. 33° E. Distance of standard from stern 69 feet, from iron mast 16½ feet.									
Portsmouth	13 x. 73	−·541	−·120	+·039 = +2° 15′	+·015	+·024	..	+·010 = +0° 35′	+·004
"	15 x. 73	..	−·120		..	..	−·019		
Simon's Bay, C. Good Hope	x. 74	..	−·120	..	..	..	−·019		
"	x. 75	..	−·094	..	..	..	−·023		
"	xi. 76	..	−·096	..	..	..	−·006		
SHAH.—Built S. 70° E. Distance of standard from stern 70 feet, from iron mast 17½ feet.									
Spithead	8 vii. 76	+·003	..	−·012 = −0° 42′	−·005	+·173	..		
"	4 x. 76	..	+·009		..	..	+·083		
Esquimault, Vancouver's Island.	x. 77	..	−·017	..	..	..	−·067		
Coquimbo	8 iii. 78	..	−·017	..	..	..	−·002		
Panama	11 v. 78	..	−·010	..	..	..	+·002		
RALEIGH.—Built S. 51° E. Distance of standard from stern 65½ feet, from iron mast 8¾ feet.									
Sheerness	6 vi. 74	+·195	..	−·017 = −1° 0′	−·006	+·203	..		
"	8 vi. 74	..	+·029		..	..	+·054		
Spithead	18 ix. 74	..	+·043	..	..	..	+·003		
Simon's Bay, C. Good Hope	iii. 75	..	+·043	..	..	..	+·026		
Bombay	29 x. 75	..	−·006	..	..	..	−·010		
Spithead	14 vi. 76	..	+·057	..	..	..	+·001		

TABLE I.—Values of the Constant Parameters P and c, Q and f, at Standard Compass Positions in Her Majesty's Ships (continued).

Geographical position.	Date of observation.	Original P.	Corrected P.	$\frac{c}{\lambda}\tan\theta$ in England.	c.	Original Q.	Corrected Q.	$\frac{f}{\lambda}\tan\theta$ in England.	f.
Iron ships cased with wood (continued).									
INCONSTANT.—Built S. 38° W. Distance of standard from stern 79 feet, from iron mast 13 feet.									
Spithead	19 viii. 69	+·297	..	+·107 = +6° 10′	+·039	−·124	..		
„ . . .	20 viii. 69	..	−·023		..	..	+·016		
Plymouth . . .	21 viii. 70	..	−·071	..	..	..	+·020		
Spithead . . .	18 xi. 71	..	−·044	..	..	..	+·017		
Rio de Janeiro .	9 i. 72	..	−·044	..	..	..	−·015		
Spithead . . .	12 x. 80	+·238	..	..	..	+·010	..		
„ . . .	14 x. 80	..	−·094*	..	..	..	−·005*		
Melbourne . .	vii. 81	..	−·150	..	..	..	+·031		
Simonoseki . .	15 xi. 81	..	−·150	..	..	..	−·041		
Simon's Bay, C. Good Hope . .	v. 82	..	−·131	..	..	..	−·020		
Iron troopships.									
EUPHRATES.—Built N. 67° W. Distance of standard from stern 96 feet, from iron mast 33¾ feet.									
Birkenhead . .	16 v. 67	−·239	..	+·079 = 4° 30′	+·027	−·267	..		
„ . . .	18 v. 67	..	−·226		..	..	+·019		
Spithead . . .	18 vi. 67	..	−·172	..	..	..	+·004		
Simon's Bay, C. Good Hope . .	31 vii. 67	..	−·159	..	..	..	+·092		
Suez	10 i. 68	..	−·156	..	..	..	+·097		
Spithead . . .	11 x. 71	−·245	..	..	..	−·089	..		
HIMALAYA.—Built . . . . . . Distance of standard from stern 64 feet.									
Spithead	8 iii. 67	−·077	..	+·017 = +1° 0′	+·007	+·270	..	+·015 = +0° 52′	+·006
„ . . .	15 iii. 67	..	−·048		..	..	+·035		
Plymouth . . .	2 vii. 72	..	−·030	..	..	..	−·061		
Simon's Bay, C. Good Hope . .	viii. 72	..	−·030	..	..	..	−·042		
Plymouth . . .	9 xi. 74	..	−·021	+·015 = +0° 52′	+·006	..	−·058		
Simon's Bay, C. Good Hope . .	18 i. 75	..	−·021		..	..	−·081		
Plymouth . . .	18 vi. 75	..	−·031	..	..	..	−·081		
ORONTES.—Built N. 68° W. Distance of standard from stern 66 feet, from iron mast 9 feet.									
Birkenhead . .	26 i. 76	−·084	..	+·074 = +4° 15′	+·029	−·202	..		
Spithead . . .	2 iii. 76	..	−·042		..	..	+·018		
„ . . .	5 ix. 79	..	−·058	..	..	..	+·084		
Simon's Bay, C. Good Hope . .	x. 79	..	−·058	..	..	..	+·034		
Mauritius . . .	xi. 79	..	−·044	..	..	..	+·094		

* After re-correction by a permanent magnet.

TABLE I.—Values of the Constant Parameters P and *c*, Q and *f*, at Standard Compass Positions in Her Majesty's Ships (continued).

Geographical position.	Date of observation.	Original P.	Corrected P.	$\frac{c}{\lambda}\tan\theta$ in England.	*c*.	Original Q.	Corrected Q.	$\frac{f}{\lambda}\tan\theta$ in England.	*f*.
Steel and iron ships cased with wood.									
COMUS.—Built S. 11° W. Distance of standard from stern 50 feet, from iron mast 7¾ feet.									
Sheerness	14 xi. 79	+·246	..	+·089 =	+·034	−·029	..	−·010 =	−·004
„	18 xii. 79	+·234	+·009	+5° 7′	..	+·041	+·022	−0° 35′	
Simon's Bay, C. Good Hope	20 iii. 80	..	−·042	..	..	..	+·038		
Hong Kong	12 vii. 80	..	−·042	..	..	..	+·038		
Singapore	13 xii. 81	..	−·017	..	..	..	+·035		
CARYSFORT.—Built S. 11° W. Distance of standard from stern 50 feet, from iron mast 7·9 feet.									
Sheerness	5 x. 80	+·262	..	+·111 =	+·044	−·014	..		
„	6 x. 80	..	−·099	+6° 23′	..	..	−·024		
Simon's Bay, C. Good Hope	1 iv. 81	..	−·133	..	..	..	+·030		
Kobé, Japan	10 xi. 81	..	−·133	..	..	..	+·007		
CLEOPATRA.—Built S. 11° W. Distance of standard from stern 49½ feet, from iron mast 6¾ feet.									
Plymouth	15 ix. 80	+·057	..	+·082 =	+·032	+·050	..		
„	17 ix. 80	..	−·033	+4° 43′	..	..	+·031		
Monte Video	31 xii. 80	..	−·074	..	..	..	−·028		
Hong Kong	20 xii. 81	..	−·074	..	..	..	+·039		
Composite vessels.									
RUBY.—Built N. 3° W. Distance of standard from stern 50 feet, from iron mast 6¾ feet.									
Sheerness	30 vi. 77	−·486	..	+·077	+·027	−·109	..		
„	3 vii. 77	..	−·086	+4° 25′	..	..	−·009		
Gulf of Xeros	iii. 78	..	−·083	..	..	..	+·003		
Singapore	vi. 78	..	−·083	..	..	..	+·018		
Rangoon	x. 79	..	−·101	..	..	..	−·028		
Zanzibar	12 iii. 80	..	−·076	..	..	..	−·009		
GANNET.*—Built S. 76° E. Distance of standard from stern 38 feet.									
Sheerness	29 iv. 79	+·122	..	+·065 =	+·024	+·139	..		
„	30 iv. 79	..	−·012	+3° 45′	..	..	+·010		
Coquimbo	x. 79	..	−·059	..	..	..	−·032		
Esquimault, Vancouver Island	vii. 81	..	−·059	..	..	..	−·014		
ALBATROSS.*—Built S. 50° E. Distance of standard from stern 37½ feet.									
Sheerness	17 xii. 73	+·209	..	+·073 =	+0·29	+·100	..		
„	20 iii. 74	..	−·066	+4° 12′	..	..	+·015		
Rio de Janeiro	5 vii. 74	..	−·066	..	..	..	−·017		
Plymouth	10 x. 74	..	−·064	..	..	..	+·022		
Taboga	27 x. 75	..	−·091	..	..	..	−·006		
Pisco	15 xii. 76	..	−·093	..	..	..	+·002		
Esquimault, Vancouver Island	29 x. 77	..	−·093	..	..	..	+·016		

---

* These vessels have wooden masts.

TABLE I.—Values of the Constant Parameters P and c, Q and f, at Standard Compass Positions in Her Majesty's Ships (continued).

Geographical position.	Date of observation.	Original P.	Corrected P.	$\frac{c}{\lambda}\tan\theta$ in England.	c.	Original Q.	Corrected Q.	$\frac{f}{\lambda}\tan\theta$ in England.	f.
Composite vessels (continued).									
BOXER.*—Built S. 60° W. Distance of standard from stern 30½ feet.									
Greenhithe . .	30 xi. 68	+·124	−·004	+·062 = +3° 35′	+·023	−·150	−·022		
Rio de Janeiro .	20 ii. 69	..	−·016		..	..	−·105		
Esquimault, Vancouver's Island	5 x. 69	..	−·008	..	..	..	−·049		
Komax, Vancouver's Island .	24 iv. 71	..	−·029	..	..	..	−·058		
Esquimault . .	30 xii. 74	..	−·004	..	..	..	−·030		
Coquimbo . . .	13 v. 75	..	−·004	..	..	..	−·003		
PERT.*—Built S. 65° W. Distance of standard from stern 29¾ feet.									
Devonport . .	3 ii. 70	+·170	..	+·070 = +4° 0′	+·026	−·174	..		
" . .	8 ii. 70	..	−·056		..	..	−·016		
Elephant Bay, W. C. Africa . .	29 xii. 70	..	−·056	..	..	..	−·051		
Rio de Janeiro .	29 xii. 71	..	−·043	..	..	..	−·054		
FIREFLY.*—Built N. 26° E. Distance of standard from stern 15¾ feet.									
Plymouth . . .	24 vi. 79	−·332	+·004	+·012 = +0° 42′	+·005	..	+·015		
Simon's Bay, C. Good Hope . .	29 v. 80	..	+·004		..	..	+·001		
Gaboon River, W. C. Africa .	30 viii. 80	..	+·032	..	..	..	+·046		
WRANGLER.*—Built N. 45° E. Distance of standard from stern 15¾ feet.									
Plymouth . .	26 v. 81	−·183	−·017	+·006 = +0° 20′	+·002	+·323	+·004		
Simon's Bay, C. Good Hope . .	31 xii. 81	..	−·017		..	..	+·027		
Wooden corvettes with iron beams and iron vertical bulkheads from keel to lower deck.									
ENCOUNTER.—Built S. 76° E. Distance of standard from stern 48 feet. Masts wooden.									
Sheerness . . .	2 ix. 73	+·182	..	+·046 = +2° 40′	+·018	+·148	..		
"	9 ix. 73	..	+·016		..	..	+·034		
Simon's Bay, C. Good Hope . .	11 iv. 74	..	+·002	..	..	..	+·022		
" . .	15 x. 74	..	−·002	..	..	..	+·007		
" . .	20 i. 76	..	−·048	..	..	..	−·001		
Grenada . . .	30 x. 76	..	−·048	..	..	..	−·014		
SAPPHIRE.—Built East. Distance of standard from stern 47¾ feet, from iron mast 5½ feet.									
Plymouth . . .	21 viii. 75	+·202	..	+·117 = +6° 45′	+·045	+·115	..		
"	24 viii. 75	..	−·093		..	..	+·012		
Simon's Bay, C. Good Hope . .	30 xi. 75	..	−·093	..	..	..	+·013		
Wellington, N.Z.	xii. 76	..	−·107	..	..	..	+·001		
Sydney, N.S.W.	viii. 77	..	−·152	..	..	..	−·033		

* These vessels have wooden masts.

TABLE II.—Table of Terrestrial Magnetic Elements for the Year 1880, used in the computations.

Geographical position.	Inclination θ.	Approximate annual change.	Absolute horizontal force in British units.	Approximate annual change.
Greenwich	+67° 36′	− 1′·7	3·915	+·005
Gibraltar	+55 43	− 4·5	5·259	+·007
Maderia	+56 0	− 5·0	5·282	+·006
Gaboon River	−15 0	−12·0	6·50	−·012
Elephant Bay	−39 12	..	5·40	..
Simon's Bay, C. Good Hope	−56 28	− 5·0	4·270	−·007
Quebec	+77 0	..	2·97	..
Rimouski	+77 52	..	2·85	..
Halifax, N.S.	+74 48	− 1·8	3·388	+·002
Bermuda	+65 0	..	5·115	+·002
St. Lucia	+43 50	..	6·75	..
Dominica	+45 48	..	6·67	..
Grenada	+41 20	..	6·85	..
Trinidad	+39 40	..	6·89	..
Rio de Janeiro	−10 46	+ 3·0	5·66	−·016
Monte Video	−29 10	+ 8·5	5·745	−·017
Sandy Point, Magellan Straits	−52 20	+11·0	6·056	−·004
27½° N., 62¾° W.	+60 0	..	5·70	..
Equator, and 24½° W.	+15 7	− 9·0	6·40	−·007
23° S., 39° W.	−11 52	+ 2·0	5·51	−·016
40½° S., 78¾ W.	−44 8	..	6·20	..
1° S., 26° W.	+16 42	− 9·0	6·40	−·007
Valparaiso	−33 39	+ 5·0	6·078	−·018
Coquimbo	−29 12	+ 4·0	6·14	−·017
Pisco	− 7 44	..	6·69	−·013
Panama	+31 57	..	7·560	−·004
Esquimault, Vancouver Island	+71 54	..	4·21	..
9¼ S., 80¾° W.	− 3 15	..	7·0	..
20 N., 157° W.	+37 58	..	6·64	..
Komax, Vancouver Island	+71 37	..	4·27	..
Gulf of Xeros	+55 23	..	5·49	..
Suez	+40 47	− 1·0	6·50	..
Zanzibar	−36 0	..	6·205	..
Mauritius	−56 23	− 1·0	5·158	−·002
Bombay	+19 29	+ 1·2	8·10	+·003
Rangoon	+17 44	..	8·15	..
6° N., 96° E.	− 5 10	..	8·30	..
Singapore	−13 11	− 0·2	8·251	+·004
Hong Kong	+32 40	+ 4·2	7·794	+·006
Yokohama	+49 12	+ 3·4	6·417	..
Kobé, Japan	+48 48	+ 3·5	6·56	..
Simonoseki	+48 40	+ 4·0	6·64	..
49° N., 149° E.	+62 30	..	5·00	..
38° N., 136° E.	+53 5	..	6·19	..
34° N., 133½° E.	+46 8	..	6·60	..
12¾° N., 46° E.	+ 5 52	..	7·50	..
Melbourne	−67 5	Stationary	5·117	−·002
Sydney, N.S.W.	−62 44	Stationary	5·754	−·003
Wellington, N.Z.	−65 12	− 1·0	5·266	...

The + sign indicates north inclination or dip, the − sign that of south dip. The correction for annual change of the inclination or dip is to be applied algebraically.

TABLE III.—Coefficients.

Place.	Date.	Approximate coefficients.					Exact coefficients.					Maximum of semi-circular deviation. $\sqrt{B^2+C^2}$	Mean horizontal force of ship. $\sqrt{\mathfrak{B}^2+\mathfrak{C}^2}$		Mean force to north.	$\frac{1}{\lambda}$	Coefficients of horizontal induction.		Part of $\mathfrak{B}$ from		Mean vertical force.	Heeling coefficient to windward.	Heeling coefficient for		Variable part of vertical force.	
		A.	B.	C.	D.	E.	$\mathfrak{A}$.	$\mathfrak{B}$.	$\mathfrak{C}$.	$\mathfrak{D}$.	$\mathfrak{E}$.	Amount.		Direction.	λ.		Headward. $\mathfrak{a}$.	To starboard. $\mathfrak{e}$.	Fore and aft induction.	Transverse induction.	μ.		Vertical induction in transverse iron.	Vertical force and induction in vertical iron.	$\frac{g}{\tan\theta}$	g.
		° ′	° ′	° ′	° ′	° ′						°		°					° ′	° ′		° ′	° ′	° ′		
Iron armour-plated ships.																										
BELLEROPHON.—Iron screw ship, armour-plated; 7550 tons; 6520 H.P.; 13 guns. Built, Chatham; head S., 51° E.; launched, 3 iii. 66.—Standard Compass.																										
Spithead	3 xi. 73	...	From quadrant.			...	...	+·028	+·233	+·098	...	13½	·235	83												
" . . .	4 xi. 73	+ 1 11	*− 0 16*	*+ 1 3*	+ 5 12	− 0 32	+·020	*−·005*	*+·017*	+·090	−·009	1	*·018*	*100*	·878	1·139	−·043	−·201	− 1 22	+ 6 4	1·056	+ 0 42	+ 0 23	+ 0 9	+·016	+·040
Halifax, N.S. . .	5 viii. 74	− 0 8	*+ 2 20*	*− 0 50*	+ 6 9	...	−·002	*+·041*	*−·014*	+·107	...	2½	*·044*	*344*												
Quebec	16 ix. 74	− 0 36	*− 0 11*	*− 2 26*	+ 5 16	+ 1 30	−·011	*−·003*	*−·049*	+·092	+·026	2½	*·041*	*265*												
Trinidad . . .	1 iii. 76	+ 0 1	*− 0 45*	*− 0 21*	+ 5 39	+ 0 26	+·001	*−·013*	*−·006*	+·098	+·008	0¾	*·015*	*199*												
Halifax, N.S. . .	21 vi. 76	− 0 28	*− 1 30*	*− 1 35*	+ 6 11	− 0 37	−·006	*−·026*	*−·026*	+·136	−·011	2¼	*·037*	*224*												
Quebec	24 viii. 76	− 0 12	*− 1 40*	*− 1 25*	+ 4 30	+ 0 39	−·004	*−·029*	*−·035*	+·078	+·011	2	*·038*	*230*												
IRON DUKE.—Iron double screw ship, armour-plated; 6010 tons; 4270 H.P.; 14 guns. Built at Pembroke; head S., 29° W.; launched, 1 iii. 70.—Standard Compass.																										
Plymouth . . .	20 i. 71	+ 0 56	+34 18	−11 24	+ 5 45	+ 0 46	+·016	+·596	−·180	+·100	+·013	36	·624	343												
" . . .	16 ix. 71	+ 1 9	*+ 7 31*	*+ 3 11*	+ 6 23	− 0 2	+·020	*+·137*	*+·052*	+·112	−·001	8¼	*·147*	*21*	·925	1·081	+·029	−·178	+ 0 54	+ 5 29	·826	+ 0 1	+ 0 29	− 0 28		
Gibraltar . . .	x. 71	+ 0 13	*+ 3 39*	*− 0 23*	+ 6 0	− 0 5	+·004	*+·065*	*−·007*	+·104	−·001	3¾	*·065*	*354*												
6° N., 96° E. .	10 xii. 71	+ 0 33	*− 1 37*	*+ 2 57*	+ 5 40	+ 0 39	+·009	*−·029*	*+·048*	+·099	+·011	3½	*·056*	*121*												
35° N., 136° E.	22 viii. 72	− 0 56	*+ 0 35*	*+ 0 27*	+ 5 17	+ 0 22	−·017	*+·010*	*+·007*	+·092	+·006	0¾	*·012*	*35*												
49° N., 140° E.	viii. 73	+ 0 52	*+ 2 12*	*+ 1 27*	+ 4 48	− 0 10	+·015	*+·040*	*+·024*	+·084	−·003	2¾	*·047*	*31*												
34° N., 123½° E	27 vii. 74	+ 0 30	*− 0 26*	*+ 2 0*	+ 4 45	+ 0 25	+·009	*−·007*	*+·033*	+·083	+·007	2	*·034*	*102*												
12½° N., 46° E.	11 iii. 75	− 2 25	*− 3 23*	*− 0 36*	+ 5 3	+ 0 34	−·042	*−·059*	*−·009*	+·088	+·010	3½	*·060*	*189*												
Plymouth . . .	27 vii. 75	− 0 12	*+ 0 38*	*+ 2 46*	+ 4 47	+ 0 13	−·003	*+·011*	*+·046*	+·083	+·004	3	*·047*	*76*												
Belfast Lough . .	5 ix. 76	− 0 27	*+ 1 0*	*+ 2 15*	+ 4 16	+ 0 7	−·007	*+·018*	*+·038*	+·074	+·002	2½	*·043*	*64*												
Plymouth* . . .	18 vii. 78	From four cardinal points.					...	+·593	−·117	...	...	36	·605	349												
" . . .	"	+ 0 8	*+ 1 26*	*− 1 25*	+ 4 57	+ 0 21	+·002	*+·036*	*−·024*	+·086	+·006	2	*·035*	*317*												
Singapore . . .	xi. 78	+ 0 1	*− 6 17*	*+ 1 1*	+ 4 56	+ 0 14	+·001	*−·114*	*+·016*	+·086	+·004	6½	*·115*	*171*												
Yokohama . . .	vii. 79	− 1 40	*− 3 0*	*− 0 52*	+ 5 3	+ 0 31	−·029	*−·054*	*−·014*	+·088	+·009	3	*·055*	*194*												
Hong Kong . .	28 xii. 80	− 0 46	*− 3 57*	*− 0 2*	+ 4 52	+ 0 34	−·013	*−·072*	*−·001*	+·085	+·010	4	*·072*	*181*												
" . .	31 xii. 81	− 1 8	*− 3 36*	*− 1 12*	+ 4 23	+ 0 49	−·020	*−·064*	*−·020*	+·079	+·014	3¾	*·067*	*197*												
TRIUMPH.—Iron screw ship, armour-plated; 6640 tons; 5110 H.P.; 14 guns. Built on River Tyne; head S., 45° W.; launched, 29 ix. 70.—Standard Compass.																										
Plymouth . . .	18 iii. 73	− 1 9	+20 53	−10 0	+ 6 46	− 0 5	−·020	+·377	−·161	+·117	−·001	23¼	·410	337												
" . . .	"	+ 0 18	*+ 1 40*	*− 0 23*	+ 7 12	+ 0 33	+·005	*+·031*	*−·007*	+·125	+·009	1¾	*·032*	347	·839	1·192	−·056	−·286	− 1 56	+ 9 7	·881	+ 0 26	+ 0 47	− 0 21	+·067	+·167
Spithead† . . .	15 v. 78	...	From S. W. quadrant.			...	...	+·266	−·063	...	...	15	·273	347												
" . . .	"	− 1 23	*− 2 7*	*+ 0 51*	+ 5 51	− 0 53	−·024	*−·039*	*+·014*	+·102	−·015	2¼	*·041*	*100*												
Equator, long. 24½° W. . . .	20 vi. 78	− 2 29	*− 7 0*	*− 0 56*	+ 7 6	− 0 58	−·043	*−·129*	*−·015*	+·124	−·017	7	*·130*	*187*												
23° S., 30° W. . .	1 vii. 78	− 3 31	*−11 13*	*+ 0 35*	+ 6 41	− 0 44	−·061	*−·205*	*+·010*	+·116	−·013	11¼	*·205*	*177*												
40½° S., 78¾° W. .	7 viii. 78	+ 0 49	*−14 51*	*+ 0 55*	+ 6 39	− 1 19	+·014	*−·271*	*+·015*	+·116	−·023	15	*·272*	*177*												
Valparaiso . . .	ix. x. 78	− 0 29	*−12 14*	*+ 0 14*	+ 6 30	− 0 20	−·008	*−·224*	*+·004*	+·113	−·006	12¼	*·224*	*179*												
9½° S., 80½° W. .	7 ii. 79	+ 1 31	*− 7 26*	*− 0 11*	+ 6 55	+ 0 16	+·026	*−·136*	*−·003*	+·120	+·005	7½	*·136*	*181*												
20° N., 157° W. .	4 iv. 79	− 1 51	*− 2 2*	*− 0 51*	+ 6 25	− 0 42	−·032	*−·037*	*−·014*	+·112	−·012	2¼	*·040*	*201*												
Esquimault. . .	v. 79	—	From S. W. quadrant.			...	...	*+·103*	*+·015*	...	...	5¾	*·104*	*8*												

* After repair at Birkenhead. Compass re-corrected at Plymouth. † Compass re-corrected on this day.

NOTE.—The values of B. and C., &c., printed in italics have been computed from the tables of deviation observed after the compass had been corrected by magnets.

TABLE III.—Coefficients (continued).

Place.	Date.	Approximate coefficients. A.	B.	C.	D.	E.	Exact coefficients. 𝔄.	𝔅.	ℭ.	𝔇.	𝔈.	Maximum of semicircular deviation. $\sqrt{\mathfrak{B}^2+\mathfrak{C}^2}$ Amount.	Mean horizontal force of ship. $\sqrt{\mathfrak{B}^2+\mathfrak{C}^2}$ Direction.	Mean force to north. λ.	$\frac{1}{\lambda}$.	Coefficients of horizontal induction. Headward. a.	To starboard. e.	Part of 𝔅 from Fore and aft induction.	Transverse induction.	Mean vertical force. μ.	Heeling coefficient to windward.	Heeling coefficient for Vertical induction in transverse iron.	Vertical force and induction in vertical iron.	Variable part of vertical force. $\frac{z}{\tan\theta}$	p.
		° ′	° ′	° ′	° ′	° ′						°	°					° ′	° ′		° ′	° ′	° ′		
***Iron armour-plated ships* (continued).**																									
SWIFTSURE.—Iron, screw ship, armour plated; 6910 tons: 4910 H.P.; 18 guns. Built on River Tyne; head S., 56° W; launched, 15 vi. 70.—Standard Compass.																									
Plymouth	17 vi. 72	From southern and west semicircles.					...	+·366	−·186	+·122	...	25½	·430	237	·834	1·199	−·064	−·268	−2 11	+9 13	1·184	+1 21	+0 48	+0 33	+·062	+·155
"	8 v. 82	...	From N.E. quadrant.			...	...	+·230	...	+·106	ass.	13¼	·229	...												
"	"	+0 33	+2 5	−0 29	+6 12	+0 22	+·009	+·036	−·006	+·108	+·006	9	·039	351	·876	1·141	−·030	−·218	−0 56	+7 8	1·108	+0 52	+0 36	+0 15	+·068	+·156
1° S., 26° W.	22 vi. 82	+1 5	−5 0	−0 13	+6 19	+0 46	+·019	−·009	−·004	+·110	+·013	5	·009	185							·872			−0 21		
23° S., 43° W.	5 vii. 82	−4 1	−11 8	−4 10	+5 44	+0 17	−·070	−·202	−·068	+·100	+·006	12	·213	190												
Monte Video	23 vii. 82	−8 21	−14 6	−1 40	+4 49	−0 9	−·061	−·255	−·027	+·094	−·002	14¾	·255	186												
Sandy Point, Magellan Straits	4 viii. 92	−1 54	−18 22	−1 7	+6 2	−1 34	−·038	−·337	−·018	+·105	−·027	19¾	·337	183												
NORTHAMPTON.—Iron double screw ship, armour-plated; 7630 tons; 6070 H.P.; 12 guns. Built at Glasgow; head S., 6° E.; launched, 18 xi. 76.—Standard Compass.																									
Sheerness	1 xi. 79	−0 44	+20 1	−0 37	+3 55	−0 6	−·018	+·354	−·010	+·063	−·002	20	·354	359	·834	1·199	−·114	−·218	−3 54	+7 32	·903	+0 21	+0 37	−0 16	+·055	+·132
Spithead	16 xii. 79	+0 37	+0 1	−0 6	+4 3	−0 1	+·011	+·001	−·009	+·070	−·001	0½	·009	280												
27½° N., 62½° W.	23 i. 80	+1 12	+0 21	−2 30	+3 44	−0 16	+·021	+·006	−·044	+·085	−·004	2½	·044	278												
St. Lucia, S.W. Point	20 ii. 80	+0 58	+0 17	−3 4	+3 30	+0 22	+·017	+·005	−·051	+·061	+·006	3	·051	276												
Bermuda	6 v. 80	−1 53	+1 12	−4 58	+5 3	−0 40	−·034	+·022	−·089	+·088	−·012	5	·086	285												
Halifax, N.S.	27 vi. 80	+0 36	−3 10	−3 2	+3 40	−1 32	+·010	−·057	−·051	+·064	−·027	4½	·077	222												
Rimouski River, St. Lawrence	31 viii. 80	−1 38	−2 17	−4 39	+3 42	−0 31	−·028	−·041	−·076	+·064	−·009	5	·087	241												
Halifax, N.S.	1 x. 80	−1 1	−2 39	−4 50	+3 40	−0 18	−·018	−·046	−·081	+·064	−·004	5½	·093	241												
Dominica	22 i. 81	−1 37	+0 23	−0 10	+4 1	−0 18	−·028	+·007	−·003	+·070	−·005	0½	·008	336												
NELSON.—Iron, double screw ship, armour-plated; 7630 tons; 6640 H.P.; 12 guns. Built at Glasgow; head S., 21° E; launched 4 xi. 76.—Standard Compass.																									
Sheerness	28 vii. 81	−0 8	+16 30	−4 7	+4 0	+0 7	−·001	+·296	−·072	+·070	+·002	17	·305	347	·830	1·204	−·112	−·228	−3 52	+7 52	·952	+0 31	+0 30	−0 8		
Plymouth	26 ix 81	−0 23	−0 12	+1 57	+4 7	−0 5	−·007	−·004	+·033	+·071	−·001	2	·033	97												
Madeira	11 x. 81	−0 6	+0 55	+0 51	+3 47	−0 24	−·002	+·016	+·015	+·066	−·007	1¼	·022	43												
Simon's Bay, C. Good Hope	14 xi. 81	−0 44	+4 35	+2 34	+3 37	−0 12	−·013	+·089	+·044	+·063	−·003	5¾	·099	26												
Iron ships cased with wood.																									
ACTIVE.—Iron cased with wood; 3080 tons; 4130 H.P.; 12 guns. Built at Blackwall; head N., 33° E; launched, 13 ii. 69.—Standard Compass.																									
Portsmouth	26 ii. 70	{ From deviation and force on one point }					...	−·540	−·064	+·085	ass.	32	·544	187							{ 1·096	+0 44	+0 26	+0 18	...	ass.
"	7 iii. 70	−0 10	−2 35	+0 49	+4 0	−0 8	−·003	−·046	+·012	+·070	−·002	3	·048	165½	·904	1·106	−·038	−·159	−1 4	+5 4	{ ·864	+0 2	+0 26	−0 24	...	
"	13 x. 73	...	From quadrant			...	...	−·537	−·016	+·059	...	32½	·537	182	·941	1·063	−·004	−·114	−0 7	+3 34	1·052	+0 26	+0 16	+0 8	...	
"	15 x. 73	+0 24	−4 59	−0 34	+3 17	−0 5	+·007	−·089	−·010	+·057	−·001	5	·090	186							·949	+0 1	+0 18	−0 17	...	
Simon's Bay	x. 74	−1 27	−7 51	−1 31	+2 41	+0 59	−·025	−·140	−·025	+·047	+·017	8	·142	190												
"	x. 75	−1 16	−6 35	−1 33	+2 14	−0 18	−·022	−·115	−·028	+·039	−·005	6¾	·118	194												
"	xi. 76	−2 12	−6 38	−0 49	+2 44	−0 18	−·036	−·117	−·019	+·046	−·005	6¾	·118	189												

TABLE III.—Coefficients (continued).

Place.	Date.	Approximate coefficients.					Exact coefficients.					Maximum of semicircular deviation. $\sqrt{B^2+C^2}$ Mean horizontal force of ship. $\sqrt{\mathfrak{B}^2+\mathfrak{C}^2}$		Mean force to north. λ.	$\frac{1}{\lambda}$.	Coefficients of horizontal induction.		Part of $\mathfrak{D}$ from		Mean vertical force. μ.	Heeling coefficient to windward.	Heeling coefficient for		Variable part of vertical force.	
		A.	B.	C.	D.	E.	$\mathfrak{A}$.	$\mathfrak{B}$.	$\mathfrak{C}$.	$\mathfrak{D}$.	$\mathfrak{E}$.	Amount.	Direction.			Headward. a.	To starboard. e.	Fore and aft induction.	Transverse induction.			Vertical induction in transverse iron.	Vertical force and induction in vertical iron.	$\frac{g}{\tan\theta}$.	g.
		° ′	° ′	° ′	° ′	°						°	°					° ′	° ′		° ′	° ′	° ′		
Iron ships cased with wood (continued).																									
Shah.—Iron cased with wood; 6050 tons; 7480 H.P.; 26 guns. Built at Portsmouth; head S. 70° E.; launched, 10 ix. 73. Standard Compass.																									
Spithead	8 vii. 76	+ 0 8	− 0 33	+11 25	+ 5 44	+ 0 15	+·002	−·009	+·188	+·100	+·004	11¾	·188	93	·923	1·083	+·005	−·159	+0 12	+4 54	·986	−0 24	+0 26	−0 2	+·011	+·027
,,	4 x. 76	− 1 29	− 0 8	+ 5 25	+ 5 5	+ 0 33	−·028	−·009	+·090	+·089	+·009	5½	·090	91												
Esquimault	x. 77	+ 0 8	− 1 49	− 4 6	+ 5 15	+ 0 20	+·002	−·033	−·068	+·091	+·006	4¾	·076	244												
Coquimbo	8 iii. 78	...	− 0 31	− 0 2	+ 5 37	+ 0 30	...	−·009	−·001	+·095	+·009	0½	·009	186												
Panama	11 v. 78	− 0 2	− 0 31	+ 0 5	+ 5 18	+ 0 38	−·001	−·009	+·001	+·091	+·011	0½	·009	174												
Ralegh.—Iron cased with wood; 5200 tons; 5640 H.P.; 22 guns. Built at Chatham; head S. 51° E.; launched, 1 iii. 73. Standard Compass.																									
Sheerness	6 vi. 74	+ 0 39	+11 46	+15 15	+ 8 0	− 0 28	+·011	+·217	+·244	+·140	−·008	20	·326	48	·833	1·200	−·072	−·262	− 2 29	+ 9 2	{·930 {·772	+ 0 33 + 0 6	+ 0 47	−0 14} −0 41}	−·017	−·042
,,	8 vi. 74	+ 0 39	+ 1 1	+ 3 50	+ 6 33	+ 0 35	+·011	+·018	+·065	+·114	+·010	4	·067	74												
Spithead	18 ix. 74	− 0 6	+ 2 1	+ 0 16	+ 6 55	− 0 36	−·002	+·035	+·004	+·120	−·010	2	·037	6												
Simon's Bay	iii. 75	− 1 14	+ 3 17	+ 1 44	+ 6 25	− 0 55	−·021	+·059	+·036	+·116	−·016	3½	·065	36												
Bombay	29 x. 75	+ 1 14	− 0 16	− 0 27	+ 5 59	+ 0 18	+·021	−·006	−·006	+·105	+·005	0½	·008	225												
Spithead	14 vi. 76	+ 0 58	+ 2 53	+ 0 3	+ 5 19	+ 1 4	+·017	+·053	+·001	+·094	+·019	3	·053	1												
Inconstant.—Iron cased with wood; 5780 tons; 7360 H.P.; 16 guns. Built at Pembroke; head S. 35° W.; launched, 12 xi. 68. Standard Compass.																									
Spithead	19 viii. 69	+ 0 56	+24 54	− 8 40	+ 4 55	− 0 22	+·016	+·441	−·140	+·085	−·006	26½	·463	342	·890	1·123	−·035	−·185	−1 6	+ 6 2	·927	+ 0 2	+ 0 31	− 0 29	+·042	+·105
,,	20 viii. 69	+ 0 13	− 4 26	+ 1 6	+ 4 52	+ 0 15	+·004	+·083	+·018	+·085	+·004	5	·085	12												
Plymouth	21 viii. 70	+ 0 48	+ 1 30	+ 1 28	+ 4 48	+ 0 3	+·014	+·027	+·023	+·084	+·001	2	·035	40												
Spithead.	18 xi. 71	+ 0 7	+ 3 3	+ 1 8	+ 4 13	− 0 4	+·002	+·057	+·019	+·074	−·001	3½	·060	19												
Rio de Janeiro	9 i. 72	+ 0 42	− 2 25	− 0 40	+ 4 22	+ 0 24	+·012	−·042	−·011	+·076	+·007	2½	·044	195												
Spithead	12 x. 80	...	From N.W. quadrant.			...	...	+·374	+·011	+·068	...	22	·375	1												
,, *	14 x. 80	+ 0 55	+ 0 5	− 0 24	+ 3 54	+ 0 16	+·016	+·001	−·006	+·068	+·005	0½	·006	260							·860	+ 0 3	+ 0 25	− 0 22		
Melbourne	6 vii. 81	+ 0 18	−13 5	+ 1 37	+ 3 40	− 0 17	+·005	−·234	+·027	+·064	−·005	13	·236	173												
Simonoseki	15 xi. 81	+ 0 55	− 2 50	− 1 37	+ 3 55	...	+·016	−·050	−·027	+·066	...	3½	·058	208												
Simon's Bay	4 v. 82	− 0 20	−11 22	− 1 18	+ 3 47	+ 0 35	−·006	−·202	−·021	+·048	+·010	11½	·203	186												
Iron troopships.																									
Euphrates.—Iron screw; 6211 tons; 3000 H.P. Built at Birkenhead; head N. 67° W; launched, 24 xi. 66.—Standard Compass.																									
Birkenhead	16 v. 67	...	From semicircle.			...	...	−·201	−·314	+·008	...	21½	·370	237	·851	1·175	−·006	−·232	− 2 11	+ 7 50	1·197	+ 1 23	+ 0 44	+ 0 38		
,,	18 v. 67	+ 1 40	− 8 4	+ 1 21	+ 5 39	+ 0 43	+·029	−·147	+·022	+·098	+·013	8½	·149	171½												
Spithead	18 vi. 67	− 0 9	− 6 45	+ 0 16	+ 5 45	− 0 9	−·003	−·123	+·005	+·100	−·003	6½	·123	177½												
Simon's Bay	31 vii. 67	− 3 17	− 9 4	+ 5 44	+ 5 24	− 1 8	−·057	−·105	+·095	+·024	−·010	10½	·141	138												
Suez	10 i. 68	+ 0 9	− 4 23	+ 3 30	+ 3 40	− 0 21	+·002	−·081	+·067	+·064	−·006	6	·105	140												
Spithead	11 x. 71	...	From quadrant.			...	...	−·166	−·105	+·067	...	11½	·196	212												

* Compass re-corrected on this day.

TABLE III.—Coefficients (continued).

Place.	Date.	Approximate coefficients.					Exact coefficients.					Maximum of semicircular deviation. $\sqrt{\mathfrak{B}^2+\mathfrak{C}^2}$		Mean force to north.	$\frac{1}{\lambda}$.	Coefficients of horizontal induction.		Part of 𝔅 from		Mean vertical force.	Heeling coefficient to windward.	Heeling coefficient for		Variable part of vertical force.	
												Mean horizontal force of ship. $\sqrt{\mathfrak{B}^2+\mathfrak{C}^2}$													
		A.	B.	C.	D.	E.	𝔄.	𝔅.	ℭ.	𝔇.	𝔈.	Amount.	Direction.	λ		Headward. 𝔞	To starboard. 𝔢	Fore and aft induction.	Transverse induction.	μ.		Vertical induction in transverse iron.	Vertical force and induction in vertical iron.	$\frac{g}{\tan\theta}$.	g.
		° ′	° ′	° ′	° ′	° ′						°	°					° ′	° ′		° ′	° ′	° ′		
Iron troopships (continued).																									
HIMALAYA.—Iron screw; 4690 tons; 2500 H.P. Built, 1854, at Blackwall.—Standard Compass.																									
Spithead . . .	8 iii. 67	+ 0 8	− 3 46	+17 50	+ 3 3	+ 0 29	+·002	−·067	+·299	+·063	+·008	18	·307	103											
,, . . .	15 iii. 67	+ 1 20	− 2 6	+ 3 2	+ 2 28	+ 0 35	+·023	−·037	+·052	+·042	+·010	3½	·063	125	·945	1·068	−·016	−·096	− 0 28	+ 2 53	1·167	+ 0 41	+ 0 18	+ 0 26	+·151	+·277
Plymouth . . .	2 vii. 72	+ 1 13	− 0 55	− 2 58	+ 3 0	+ 0 14	+·021	−·016	−·049	+·052	+·004	3	·051	252	·950	1·068	...	−·100	—	+ 3 0	1·119	+ 0 34	+ 0 16	+ 0 13	+·007	+·017
Simon's Bay . .	viii. 72	− 0 50	− 2 51	− 2 53	+ 2 57	− 0 18	−·014	−·046	−·049	+·051	−·005	3¼	·067	227											
Plymouth . . .	9 xi. 74	+ 0 25	− 0 23	− 2 42	+ 2 49	+ 0 9	+·007	−·013	−·046	+·049	+·003	2¾	·047	260											
Simon's Bay . .	18 i. 75	− 0 56	− 1 37	− 4 56	+ 2 58	− 0 2	−·016	−·030	−·085	+·052	−·001	5¼	·091	251											
Plymouth . . .	18 vi. 75	+ 0 36	− 0 51	− 4 0	+ 2 46	− 0 12	+·010	−·016	−·069	+·048	−·004	4¼	·071	257											
ORONTES.—Iron screw; 5920 tons; 2570 H.P. Built at Birkenhead; head N. 66° W; launched, 22 xi. 62.—Standard Compass.																									
Birkenhead . .	26 i. 76	− 0 12	− 0 54	−12 57	+ 3 5	+ 0 8	−·004	−·016	−·218	+·064	+·002	13	·219	266											
Spithead . . .	2 iii. 76	+ 1 1	+ 1 41	+ 1 19	+ 3 31	+ 0 16	+·017	+·030	+·020	+·061	+·006	2	·040	34											
,, . . .	5 ix. 79	− 0 46	+ 0 46	+ 5 34	+ 3 17	+ 0 4	−·013	+·013	+·091	+·057	+·001	5¼	·092	82											
Simon's Bay . .	x. 79	− 3 21	− 5 40	+ 2 1	+ 3 34	− 0 12	−·058	−·109	+·034	+·062	−·002	6	·108	162											
Mauritius . . .	xi. 79	− 0 56	− 4 21	+ 4 26	+ 3 39	+ 0 13	−·016	−·078	+·076	+·064	+·004	6¼	·109	136											
Iron and steel ships cased with wood.																									
COMUS.—Iron and steel screw corvette, cased with wood; 2380 tons; 2450 H.P.; 14 guns. Built, Glasgow; head S. 11° W; launched, 3 iv. 78.—Standard Compass.																									
Sheerness . . .	14 xi. 79	...	From N.W. quadrant.			...	...	+·354	−·041	+·098	...	20¾	·354	353	·937						·906	+ 0 25	+ 0 26	− 0 1		
,, . . .	15 xi. 79	+ 0 50	− 0 8	+ 0 49	+ 6 9	+ 0 34	+·014	−·001	+·013	+·107	...	0¾	·014	94	·932	1·073	+·033	−·169	+ 1 0	+ 5 9	·977	+ 0 22	+ 0 26	− 0 04		
,, . . .	18 xii. 79	...	From north semicircle.				...	+·342	+·080	+·107	...	20½	·346	5							·796	− 0 5		− 0 31		
,, * . . .	19 xii. 79	+ 0 17	+ 5 26	+ 0 59	+ 6 9	+ 0 15	+·005	+·099	+·014	+·107	+·004	5¾	·100	8											
Simon's Bay . .	20 iii. 80	+ 0 21	− 5 17	+ 2 36	+ 5 52	− 0 19	+·006	−·097	+·044	+·102	−·005	6	·106	155											
Hong-Kong . .	12 vii. 80	+ 0 7	+ 0 2	+ 1 6	+ 6 8	+ 0 37	+·002	+·001	+·018	+·107	+·011	1	·018	87											
Singapore . . .	12/13 xii. 81	− 0 17	− 0 1	+ 1 18	+ 5 40	+ 0 42	−·005	−·001	+·019	+·099	+·012	1¼	·019	90											
CARYSFORT.—Iron and steel screw corvette, cased with wood, 2380 tons; 2400 H.P.; 14 guns. Built, Glasgow; head S. 11° W.; launched, 26 ix. 78.—Standard Compass.																									
Sheerness . . .	5 x. 80	From southern semicircle.					...	+·387	−·015	...	...	21	·387	358											
,, . . .	6 x. 80	− 0 29	+ 0 22	− 1 30	+ 5 23	+ 0 18	−·008	+·006	−·025	+·094	+·005	1½	·026	294	·950	1·052	+·020	−·139	+ 1 13	+ 4 10	·897	+ 0 5	+ 0 21	− 0 26	+·040	+·096
Simon's Bay . .	1 iv. 81	− 0 50	−10 58	+ 1 48	+ 5 8	− 0 8	−·014	−·198	+·029	+·089	−·002	11	·200	172											
Kobé, Japan . .	10 xi. 81	− 0 50	− 1 51	+ 0 14	+ 5 0	− 0 16	−·014	−·033	+·004	+·087	−·005	1¾	·033	173											
CLEOPATRA.—Steel and iron screw corvette, cased with wood; 2380 tons; 2610 H.P.; 14 guns. Built, Glasgow; head S. 11° W.; launched, 1 viii. 78.—Standard Compass.																									
Devonport . . .	15 ix. 80	From southern semicircle.					...	+·143	+·054	+·109	...	8¼	·153	21											
,, . . .	17 ix. 80	+ 0 25	+ 2 32	+ 2 5	+ 6 16	− 0 35	+·007	+·046	+·094	+·109	−·010	3¾	·067	37							·942	+ 0 17	+ 0 27	− 0 10		
Monte Video . .	10/11 xii. 80	− 0 26	− 4 2	− 1 17	+ 6 26	+ 0 34	−·007	−·074	−·021	+·112	+·010	4¼	·077	196											
Hong-Kong . .	20 xii. 81	− 0 6	− 1 0	+ 1 15	+ 6 19	+ 0 49	−·002	−·018	+·021	+·110	+·014	1¾	·028	130											

* Compass re-corrected on this day.

TABLE III.—Coefficients (continued).

Place.	Date.	Approximate coefficients.					Exact coefficients.					Maximum of semicircular deviation. $\sqrt{B^2+C^2}$ Mean horizontal force of ship. $\sqrt{\mathfrak{B}^2+\mathfrak{C}^2}$		Mean force to north.	$\frac{1}{\lambda}$	Coefficients of horizontal induction.		Part of $\mathfrak{B}$ from		Mean vertical force.	Heeling coefficient to windward.	Heeling coefficient for		Variable part of vertical force.	
		A.	B.	C.	D.	E.	$\mathfrak{A}$.	$\mathfrak{B}$.	$\mathfrak{C}$.	$\mathfrak{D}$.	$\mathfrak{E}$.	Amount.	Direction.	λ.		Headward. $\mathfrak{a}$.	To starboard. $\mathfrak{e}$.	Fore and aft induction.	Transverse induction.	μ.		Vertical induction in transverse iron.	Vertical force and induction in vertical iron.	$\frac{g}{\tan\theta}$.	g.
		° ′	° ′	° ′	° ′	° ′						° ′	°					° ′	° ′		°	° ′	° ′		

Composite vessels.

Ruby.—Composite screw corvette; 2120 tons; 1930 H.P.; 12 guns. Built, Hull; head N. 3° W.; launched, 10 viii. 76.—Standard Compass.

Place.	Date.	A.	B.	C.	D.	E.	$\mathfrak{A}$.	$\mathfrak{B}$.	$\mathfrak{C}$.	$\mathfrak{D}$.	$\mathfrak{E}$.	Amount.	Direction.	λ.	$\frac{1}{\lambda}$	$\mathfrak{a}$.	$\mathfrak{e}$.	Fore and aft induction.	Transverse induction.	μ.	Heeling coefficient to windward.	Vertical induction in transverse iron.	Vertical force and induction in vertical iron.	$\frac{g}{\tan\theta}$.	g.
Sheerness	30 vi. 77	From east semicircle.				...	...	−·409	−·128	...	...	25½	·430	197											
"	3 vii. 77	−0 56	−1 19	−0 45	+5 48	−0 51	−·016	−·094	−·011	+·101	−·015	1¾	·096	205	·853	1·172	−·061	−·233	−2 2	+7 50	1·444	+1 22	+0 41	+0 41	−·020	−·060
																				·941	+0 30		−0 10		
Gulf of Xeros	iii. 78	−0 44	−1 18	+0 7	+6 9	−0 6	−·013	−·024	+·002	+·107	−·002	1¾	·024	176											
Singapore	vi. 78	+0 45	−2 59	+0 38	+5 50	+0 15	+·013	−·055	+·010	+·102	+·004	3	·056	170											
Rangoon	x. 79	−0 33	−2 39	−0 58	+5 0	+0 6	−·010	−·046	−·016	+·087	+·002	2½	·049	190											
Zanzibar	12 iii. 80	+0 11	−4 20	−0 26	+4 42	+0 5	+·003	−·079	−·007	+·082	+·001	4¼	·079	185											

Gannet.—Composite screw sloop; 1130 tons; 1110 H.P.; 6 guns. Built, Sheerness; head S. 76° E.; launched, 31 viii. 78.—Standard Compass.

Place.	Date.	A.	B.	C.	D.	E.	$\mathfrak{A}$.	$\mathfrak{B}$.	$\mathfrak{C}$.	$\mathfrak{D}$.	$\mathfrak{E}$.	Amount.	Direction.	λ.	$\frac{1}{\lambda}$	$\mathfrak{a}$.	$\mathfrak{e}$.	Fore and aft induction.	Transverse induction.	μ.	Heeling coefficient to windward.	Vertical induction in transverse iron.	Vertical force and induction in vertical iron.	$\frac{g}{\tan\theta}$.	g.
Sheerness	29 iv. 79	−0 52	+11 20	+9 17	+3 22	+0 11	−·015	+·201	+·155	+·059	+·003	14½	·253	38	·895	1·117	−·052	+·158	−1 39	+5 2	·964	+0 3	+0 24	−0 21		
"	30 iv. 79	−0 43	+2 54	+0 42	+3 47	+0 7	−·012	+·059	+·019	+·066	+·002	3	·058	13											
Coquimbo	x. 79	+0 25	−3 15	−1 24	+3 55	+0 36	+·007	−·058	−·093	+·068	+·010	3½	·063	209											
Esquimault	vii. 81	−0 2	+1 17	−0 53	+3 26	−0 21	−·001	+·024	−·015	+·060	−·006	1½	·028	328											

Albatross.—Composite screw sloop; 940 tons; 840 H.P.; 4 guns. Built, Chatham; head S. 50° E.; launched, 27 viii. 73.—Standard Compass.

Place.	Date.	A.	B.	C.	D.	E.	$\mathfrak{A}$.	$\mathfrak{B}$.	$\mathfrak{C}$.	$\mathfrak{D}$.	$\mathfrak{E}$.	Amount.	Direction.	λ.	$\frac{1}{\lambda}$	$\mathfrak{a}$.	$\mathfrak{e}$.	Fore and aft induction.	Transverse induction.	μ.	Heeling coefficient to windward.	Vertical induction in transverse iron.	Vertical force and induction in vertical iron.	$\frac{g}{\tan\theta}$.	g.
Sheerness	17 xii. 73	−0 33	+16 33	+6 17	+3 59	−0 24	−·011	+·286	+·105	+·070	−·007	17¾	·315	20	·951	1·052	+·017	−·115	+0 34	+3 25	·920	−0 10	+0 18	−0 26	+·034	+·086
"	20 iii. 74	−1 31	+0 19	+0 55	+4 1	−0 6	−·026	+·005	+·016	+·070	−·002	1	·017	72											
Rio de Janeiro	5 vii. 74	−0 39	−2 55	−0 45	+4 14	+0 6	−·011	−·053	−·012	+·074	+·002	3	·054	193											
Plymouth	10 x. 74	+0 10	+0 10	+1 23	+3 28	−0 41	+·002	+·003	+·023	+·060	−·012	1¼	·023	82											
Taboga	27 x. 75	−0 20	−1 44	−0 12	+3 44	+0 9	−·006	−·031	+·003	+·065	+·003	1¾	·031	186											
Pisco	15 xii. 76	+0 31	−3 28	+0 4	+2 55	+0 41	+·009	−·061	+·001	+·051	+·012	3½	·061	179											
Esquimault	29 x. 77	−0 47	+0 16	+0 56	+3 26	−0 6	−·014	+·005	+·016	+·060	−·002	1	·017	72											

Boxer.—Composite double screw gun vessel; 608 tons; 590 H.P.; 4 guns. Built, Deptford; head S. 60° W.; launched, 25 i. 68.—Standard Compass.

Place.	Date.	A.	B.	C.	D.	E.	$\mathfrak{A}$.	$\mathfrak{B}$.	$\mathfrak{C}$.	$\mathfrak{D}$.	$\mathfrak{E}$.	Amount.	Direction.	λ.	$\frac{1}{\lambda}$	$\mathfrak{a}$.	$\mathfrak{e}$.	Fore and aft induction.	Transverse induction.	μ.	Heeling coefficient to windward.	Vertical induction in transverse iron.	Vertical force and induction in vertical iron.	$\frac{g}{\tan\theta}$.	g.
Greenhithe	30 xi. 68	...	From N.E. quadrant			...	...	+·196	−·161	+·072	...	14¾	·253	320											
"	"	+0 11	+3 11	−1 27	+3 39	+0 20	+·003	+·057	−·094	+·064	+·006	3½	·062	337											
Rio de Janeiro	20 ii. 69	−0 6	−0 49	−4 15	+3 50	−0 24	−·002	−·014	−·071	+·067	−·007	4¼	·072	259											
Esquimault	4 x. 69	−0 9	+3 49	−2 53	+2 33	−0 20	−·002	+·065	−·049	+·050	−·006	4¾	·082	323											
Komax, Vancouver Island	24 iv. 71	+1 33	+2 52	−3 27	+2 25	+0 19	+·027	+·051	−·059	+·042	+·005	4¼	·078	311											
Esquimault	30 xii. 74	−2 52	+4 4	−1 46	+3 18	+0 24	−·050	+·073	−·030	+·057	+·007	5	·079	338											
Coquimbo	13 v. 75	−1 05	−0 59	−0 5	+2 20	−0 10	+·019	−·017	−·002	+·041	−·002	1	·017	186											

Perry.—Composite double screw gun vessel; 603 tons; 500 H.P.; 4 guns. Built, Glasgow; head S. 65° W.; launched, 22 vi. 66.—Standard Compass.

Place.	Date.	A.	B.	C.	D.	E.	$\mathfrak{A}$.	$\mathfrak{B}$.	$\mathfrak{C}$.	$\mathfrak{D}$.	$\mathfrak{E}$.	Amount.	Direction.	λ.	$\frac{1}{\lambda}$	$\mathfrak{a}$.	$\mathfrak{e}$.	Fore and aft induction.	Transverse induction.	μ.	Heeling coefficient to windward.	Vertical induction in transverse iron.	Vertical force and induction in vertical iron.	$\frac{g}{\tan\theta}$.	g.
Devonport	3 ii. 70	...	From N.E. quadrant			...	...	+·251	−·186	+·068	...	18	·312	323											
"	8 ii. 70	+1 0	+0 46	−1 04	+3 50	−0 31	+·017	+·013	−·017	+·067	−·009	1¼	·021	307	·939	1·065	+·002	−·124	+0 5	+3 45						
Elephant Bay, W. Coast of Africa	29 xii. 70	+3 9	−3 30	−2 18	+2 59	...	+·055	−·062	−·038	+·052	...	4¼	·073	309											
Rio de Janeiro	29 xii. 71	−0 7	−2 0	−2 13	+3 15	−1 35	−·002	−·036	−·038	+·057	−·029	3	·052	297											

TABLE III.—Coefficients (continued).

Place.	Date.	Approximate coefficients.					Exact coefficients.					Maximum of semi-circular deviation. $\sqrt{B^2+C^2}$ Mean horizontal force of ship. $\sqrt{\mathfrak{B}^2+\mathfrak{C}^2}$		Mean force to north.	$\frac{1}{\lambda}$	Coefficients of horizontal induction.		Part of 𝔅 from		Mean vertical force.	Heeling coefficient to windward.	Heeling coefficients for		Variable part of vertical force.	
		A.	B.	C.	D.	E.	𝔄.	𝔅.	ℭ.	𝔇.	𝔈.	Amount.	Direction.	λ.		Headward. 𝔞.	To starboard. 𝔢.	Fore and aft induction.	Transverse induction.	μ.		Vertical induction in transverse iron.	Vertical force and induction in vertical iron.	$\frac{f}{\tan\theta}$.	g.
		° ′	° ′	° ′	° ′	° ′						°	°					° ′	° ′		° ′	° ′	° ′		
Composite vessels (continued).																									
FIREFLY.—Composite screw gunboat; 455 tons; 470 H.P.; 4 guns. Built, Glasgow; head N. 26° E.; launched, 26 vi. 77.—Standard Compass.																									
Plymouth	24 vi. 79	...	From	S.W. qu	adrant	...	...	−·230	...	...	...	18	·230	180											
,,	,,	+ 0 45	+ *0 55*	+ *0 57*	+ 3 45	+ 0 18	+·013	+*·016*	+*·016*	+·065	+·005	*1⅓*	·026	*45*											
False Bay, C. of Good Hope	29 vi. 80	− 0 22	− *0 14*	+ *0 4*	+ 4 6	+ 0 4	−·006	−*·004*	+*·001*	+·071	+·001	*0¼*	·004	*166*											
Gaboon R.	30 viii. 80	+ 0 32	+ *1 3*	+ *1 42*	+ 3 40	+ 0 45	+·009	+*·019*	+*·020*	+·064	+·013	*2*	·035	*57*											
WRANGLER.—Composite screw gun vessel; 465 tons; 460 H.P.; 4 guns. Built, Barrow-in-Furness; head N.E.; launched, 5 x. 80.—Standard Compass.																									
Plymouth	26 v. 81	− 0 37	−10 28	+20 26	+ 3 15	− 0 30	−·011	−·183	+·330	+·057	−·009	23	·365	117	·970	assu	med.				·942	+ 0 7	+ 0 15	− 0 15		
,,	,,	− 0 4	− *0 41*	+ *0 15*	+ 4 36	− 0 31	−·001	−*·012*	+*·004*	+·081	−·009	*0¾*	*·013*	*162*											
Simon's Bay	31 xii. 81	− 0 52	− *1 5*	− *1 58*	+ 5 2	+ 0 9	−·015	−*·020*	+*·036*	+·088	+·002	*2*	·033	*239*											
Wooden ships with iron beams and vertical bulkheads.																									
ENCOUNTER.—Wood corvette, iron beams and iron transverse bulkheads from keel to lower deck. Built at Sheerness; head S. 75° E.; launched, 6 xi. 69.—Standard Compass.																									
Sheerness	2 ix. 73	− 0 3	+13 24	+ 9 27	+ 4 12	+ 0 20	−·001	+·240	+·157	+·073	+·006	16½	·287	33	·940	1·063	+·008	−·128	+ 0 20	+ 3 53	·844	− 0 4	+ 0 20	− 0 24	+·002	+·005
,,	9 ix. 73	+ 0 35	+ *3 38*	+ *2 8*	+ 4 14	− 0 11	+·010	+*·064*	+*·036*	+·074	−·003	*4*	*·074*	*29*											
Simon's Bay	11 iv. 74	+ 1 18	− *1 56*	+ *1 19*	+ 3 40	+ 1 0	+·020	−*·026*	+*·022*	+·064	+·017	*2*	*·034*	*140*											
,,	15 x. 74	+ 0 36	− *1 10*	+ *0 37*	+ 4 42	+ 0 28	+·010	−*·021*	+*·006*	+·082	+·008	*1¼*	*·022*	*160*											
,,	20 i. 76	− 1 9	− *4 12*	− *0 12*	+ 2 48	− 0 50	−·020	−*·075*	−*·001*	+·050	−·017	*4¼*	*·076*	*185*											
Grenada	30 x. 76	+ 0 36	− *0 48*	− *0 37*	+ 3 30	− 0 23	+·010	−*·014*	−*·009*	+·059	−·006	*1*	*·016*	*218*											
SAPPHIRE.—Wood corvette, iron beams and iron transverse bulkheads from keel to lower deck. Built at Devonport; head E.; launched, 24 ix. 74.—Standard Compass.																									
Devonport	21 viii. 75	− 0 22	+18 44	+ 7 24	+ 4 7	− 0 25	−·006	+·333	+·123	+·072	−·007	20	·352	20	·938	1·066	+·005	−·129	+ 0 9	+ 3 58	·831	− 0 6	+ 0 21	− 0 27	+·013	+·032
,,	24 viii. 75	− 0 17	+ *1 3*	+ *0 46*	+ 4 9	− 0 17	−·005	+*·018*	+*·013*	+·072	−·005	*1⅓*	*·022*	*36*											
Simon's Bay	30 xi. 75	− 0 5	− *8 56*	+ *0 49*	+ 3 55	+ 0 20	−·001	−*·160*	+*·013*	+·068	+·006	*9*	*·160*	*175*											
Wellington, N. Z.	xii. 76	− 0 48	−*10 43*	+ *0 5*	+ 3 0	− 0 52	−·014	−*·189*	+*·001*	+·052	−·015	*11*	*·189*	*179*											
Sydney, N. S. W.	viii. 77	− 0 10	−*11 20*	− *1 26*	+ 3 48	+ 0 15	−·003	−*·203*	−*·024*	+·066	+·004	*12*	*·204*	*187*											

XIX. *Pelvic Characters of* Thylacoleo carnifex.

By Professor Owen, *C.B., F.R.S., &c.*

Received April 13,—Read April 26, 1883.

[Plate 46.]

Since the communication of the 1st February, 1883, "On the Affinities of *Thylacoleo*," I have received, through the favour of the Trustees of the Museum of Natural History, Sydney, and the care of the accomplished keeper, E. P Ramsay, Esq., F.L.S., a second consignment of the palæontological results of his exploration of the Breccia Caverns of Wellington Valley, New South Wales.

Besides additional confirmation of the dental, mandibular, antibrachial, ungual, and other osteal characters of *Thylacoleo*, these accessory specimens afford further evidence of the carnivorous modifications of parts of the skeleton. Of these a well-marked one is yielded by the pelvis (Plate 46, fig. 1).

I may premise that this part in *Felis* and *Macropus* shows the following differences:—

In *Macropus major* (Plate 46, fig. 2) the ilium, *i*, extends above, or anterior to, the acetabulum, *a*, into an elongate body of a triedral form: the two outer facets are deeply hollowed transversely, are separated from each other by a sharp well-produced ridge, and each is divided from the flattened and roughened mesial, or sacral, third surface by similar ridge-like productions bounding the respective margins of the outer non-articular surfaces. In *Felis* (Plate 46, fig. 3) the superacetabular body of the ilium, *i*, is a relatively broader plate of bone with the slightly concave outer surface undivided. The ilium, in *Macropus*, bends outward to its free tuberous end and contracts thereto. In *Felis* it slightly expands to the ridge-shaped free border. In *Macropus* the contour of the acetabular margin approaches a triangular figure, the truncate apex being forward or next the ilium; the basal part of the margin is cleft above the canal or groove leading from the ischium, *s*, to the bottom of the articular cavity, *a*. In *Felis* the contour of the acetabulum, *a*, is sub-circular; the iliac border is not produced into an angle. The synovial glandular pit is broader and shallower, and the mesial boundary of the canal leading thereto is not produced; the lateral boundary alone arches over part of that canal.

A marked difference between *Macropus* and *Felis* is the relative length and slenderness of the ischium, *s*, as it recedes from the acetabular region to the terminal tuberosity, s'. In the Marsupial it contributes four-fifths of the outer border of the relatively large obturator vacuity, *o*. In *Felis* the shorter, broader, and thicker body of the ischium, as it descends or retrogrades to the tuberosity, s', contributes but half of the outer border of the relatively smaller obturator foramen, *o*, the anterior third of each border running parallel with the acetabulum.

The portion of pelvis from the Wellington cave (Plate 46, fig. 1) corresponds in size, and includes the parts to which the above-defined characters of the carnivorous and herbivorous Mammals can be respectively compared. The ilium, *i*, is lamellar in form, not a triedral bar. The acetabulum, *a*, has a wide and shallow sub-circular synovial cavity, *p*, the entry to which is not encroached upon by the mesial and distal acetabular border, but is partially overarched thereby posteriorly or laterally.

The tuberosity, fig. 1, *t*, for the origin of the superacetabular tendon of the rectus femoris muscle is rather more prominent than in *Felis*, fig. 3, *t*; in *Macropus*, fig. 2, *t*, it is almost flat, and is indicated by a roughened surface.* The distance of this surface from the acetabulum is the same in the Kangaroo as is that of the process, *t*, in the cave-fossil; in the Lion it is nearer to the acetabular border.

In *Macropus major* a subquadrate process, *i*, with a basal breadth of one inch, extends for seven lines forward from the ilio-pubic commencement of the brim of the pelvis. This process does not relate to the attachment of a marsupial bone, it answers rather to the "anterior inferior spine" of the human ilium, and gives attachment to the main origin of the "rectus femoris;" it may relate, in both, to the action of that muscle in maintaining the erect, bipedal posture.

The "anterior inferior spine" is represented by a narrow rough slightly produced ridge from the same position in the leonine pelvis, and is not more developed in the cave-fossil. In this the facets, fig. 1, *m*, at the fore-end of the ischio-pubic symphysis for the attachment of marsupial bones, are present: but such surface is not upon an outwardly produced epiphysial bone, as in the full-grown *Macropus major*.

But now it may be asked—"Why is the comparison confined to the largest of the existing herbivorous Marsupials?" To which I reply that size seems to relate to the sphere of activity in which Marsupials obtain their vegetable food. Those that seek it in trees, like the arboreal Phalangers and Koalas, do not exceed a Cat or Rabbit in size, while the grazers attain a bulk which equals that of *Thylacoleo carnifex*, and the vegetarian contemporaries of that extinct species much exceeded in size the Boomer Kangaroo (*Macropus major*). Among the cave remains of the prey of *Thylacoleo* is part of a gnawed pelvis twice the size of that of the Boomer, but closely repeating the Macropodal characters of that part of the skeleton in the existing Kangaroos.†

---

* In man it is a groove, and gives attachment to the so-called "reflected tendon" of the rectus femoris.

† 'Fossil Mammals of Australia,' 4to., vol. ii., pl. cxxx. (*Palorchestes*).

I have, however, pursued my comparisons of the Thylacolean pelvis with that of smaller Marsupial vegetarians, and also with the pelvis of the existing carnivorous Marsupials, the largest of which is small in comparison with *Thylacoleo*.

In all these existing Marsupials the triedral character of the elongate ilium is retained, but in a much less marked degree than in *Macropus*. The outer dividing angle or ridge is feebly developed, and the facets it divides are not excavated, not in any of them, at least, as in the Kangaroos. The anterior end of the ilium bends outward in the Koala, and, in a greater degree, in the Wombat. The dasyurine pelvis, figs. 4, 5, resembles in the minor indication of such bend that of the cave-fossil; and also shows the relative shortness of the ischium as it extends from the acetabulum, and the characters of that cup. But both *Thylacinus* and *Diabolus* differ from *Thylacoleo* in the minor development of the superacetabular process, *t*, in the size of which the great pouched Carnivore resembles the Felines. Both, however, repeat in the mere roughened indication of the strong antacetabular process, *i*, in the Kangaroos, the character by which the Felines resemble *Thylacoleo*. The triangular facets, *m*, at the fore-end of the ischio-pubic symphysis, for the attachment of the pouch-bones are as in *Thylacoleo*.

Thus it was seen that in the points in which the Fossil differs from the Feline, it adheres to the Marsupial type, especially as shown by the larger still existing pouched Carnivores; as, for example, on the shorter extent of the ischium below the acetabulum and in its tuberous end being continued more squarely mesiad, instead of bending forward to join the pubis, as in *Felis* (fig. 3, *o*).

On the whole the fossil pelvis most resembles the dasyurine modification of this part of the skeleton, but by characters too nearly similar to those in the equipedal Diprotodonts to sanction a reference of *Thylacoleo* to the Polyprotodont group.

One character by which the larger Carnivore differs from the existing Marsupials, and agrees with the placental Carnivores, viz.: the superacetabular tuberosity, *t*, *e.g.*, indicates a disposition of powerful limb-muscles in harmony with their frequent actions in a predatory quadruped engaged in pulling down a larger vegetable-feeder. In the differential modifications of the pelvis of the terrestrial pouched grazers and browsers may be seen relations to muscular developments needed for the transfer of locomotive power, in rapid flight, to one pair of limbs, the hinder ones, in which the larger terminal horn-sheaths of the digits approach the character of hoofs. The smaller fore-paws retain the unguiculate structure, relating, in the female, to the economy of the pouch.

If the foregoing details be deemed tedious, or seem superfluous, in addition to the deductions as to the life-work of the extinct Marsupial founded on its skull, its teeth, its fore-limbs, I must plead the deserved reputation as a Comparative Anatomist of the distinguished Member of the Royal Society, who doubts the carnivority of the

Thylacoleo;[*] and the testimony which Professor **Flower** cites[†] in support of his doubts, may also have weight with many readers:—"Mr. **Gerard Krefft**, the able Curator of the Australian Museum, Sydney, in the 'Annals and Magazine of Natural History,' vol. xviii., ser. 3, p. 146, 1866, gives his opinion that '*this famous Marsupial Lion was not more carnivorous than the Phalangers of the present time.*'"

The value of this testimony I leave to the judgment of the Fellows of the Royal Society of Sydney, and of the Linnean Society of the same capital of New South Wales.[‡]

Addendum.

(Added August, 1883.)

[Since the Report by the Referees on the preceding Paper was submitted to the Council of the Royal Society, I have received from the Secretary the following remark made by one of the Referees:—

"I think the value of the Paper would be enhanced if it contained a distinct statement whether the reference of the fossil to *Thylacoleo* is inferred or based on such circumstantial evidence as leaves no room for doubt in respect to its identification."

The following is submitted in compliance with the Secretary's suggestion. The circumstantial evidence consists in the absence of any other fossils, showing a carnivorous type of dentition, agreeing in size with limb-bones of like indication and corresponding size, save jaws and teeth, of a *Thylacoleo*. The arrival, subsequent to the reading of the Paper, of Mr. **Ed. W. Ramsay**, F.L.S., as Superintendent of the Australian Department of the Fisheries Exhibition, has added, by verbal details and supplementary specimens, direct confirmation of the deductions from his previous transmission of the described fossils. If no other specimens than the limb-bones had been received they would have impressed me with the conviction that a Carnivore exceeding in size the existing Thylacine, in the degree in which the Lion surpasses the Wolf, had co-existed with the Diprotodonts, Nototheriums, and other large phytophagous Marsupials.

---

[*] "What was the particular form of food associated with the most singular dentition of *Thylacoleo*, it would be hazardous to do more than conjecture. As the flora of the country in which this strange animal existed has probably undergone as great a change as the fauna, it is not unlikely that the material on which it subsisted has passed away with the creature itself. It may have been some kind of root or bulb; it may have been fruit; it may have been flesh."

[†] "On the Affinities and probable Habits of the extinct Australian Marsupial, *Thylacoleo carnifex* **Owen**," Quarterly Journal of the Geological Society, vol. xxiv., 1868.

[‡] Proceedings of the Linnean Society of New South Wales, 8vo., 1883, p. 187 ("On Tooth-marked Bones of Extinct Marsupials," by **Charles De Vis**, B.A.).

The extirpating cause of the *Felis spelæa* together with the huger Herbivores (*Elephas, Rhinoceros, Megaceros, Bos primigenius*), represented by remains in British caverns, may be inferred to have operated in relation to the analogous evidences in Australia. That cause I conceive to have been Prehistoric Man.]

DESCRIPTION OF THE PLATE.

PLATE 46.

Fig. 1. Os innominatum,	*Thylacoleo carnifex*, nat. size.
Fig. 2. Ib.	*Macropus major*, ⅓ nat. size.
Fig. 3. Ib.	*Felis Leo*, do.
Fig. 4. Ib.	*Thylacinus cynocephalus*, ½ nat. size.
Fig. 5. Ib.	*Diabolus ursinus*, do.

XX. *The Limiting Thickness of Liquid Films.*

By A. W. REINOLD, *M.A., Professor of Physics in the Royal Naval College, Greenwich, and* A. W. RÜCKER, *M.A., Professor of Physics in the Yorkshire College, Leeds.*

Communicated by R. B. CLIFTON, *M.A., F.R.S., Professor of Experimental Philosophy in the University of Oxford.*

Received March 6,—Read April 19, 1883.

[PLATE 47.]

THE experiments described in this Paper are an extension of our previous investigations on the properties of liquid films. The interest and the difficulty of such inquiries increase as the thickness of the films diminishes, and culminate when they are sufficiently thin to show the black of the first order of NEWTON'S rings. We can in that case only infer from the colour that the thickness is less than a certain possible maximum. Our knowledge as to the real value of this maximum is, we venture to think, very uncertain, but it furnished, we believe, previous to our own investigations, the only clue to the thickness of a black liquid film.

In a Paper on the "Thickness of Soap Films" (Proc. Roy. Soc., 1877, No. 182, p. 345), we were however able to show, for the particular liquid and apparatus used :—

i. That the variations in thickness of the black portions of the films were but a small fraction of that thickness.

ii. That the thickness was independent of the breadth of the black ring.

iii. That it was also independent of the thickness of that portion of the film which appeared to the naked eye to be in immediate contact with it.

We also proved, on the assumption that the specific resistance of the liquid in the film was identical with that of the same liquid in mass, that the average thickness of the black films observed must have been 12×10^{-6} millims.

In a more recent Paper (Phil. Trans., 1881, p. 447) we have shown that this assumption is correct for thicknesses greater than 374×10^{-6} millims., below which the number of our observations was insufficient to enable us to arrive at a reliable conclusion. It was also shown that very slight changes in the temperature or hygrometric state of the air produce great variations in the composition of films formed of a mixture of soap solution and glycerine.

In order, therefore, to investigate further the properties of very thin films, it was necessary that the temperature and hygrometric state of the air in contact with the films should be more completely under control. An apparatus by which this end is obtained has been devised, and we have with it repeated our observations on the electrical resistance of black soap films, with all the advantages gained by the use of the electrometer instead of the galvanometer which was previously employed (see Phil. Trans., 1881, p. 457). These experiments were sufficient to test the constancy of the thickness of black films, but would not alone afford a trustworthy measure of its absolute value. If NEWTON's value of the thickness corresponding to the beginning of the black be accepted as correct, a black film must be at least ten times thinner than the thinnest for which we have directly proved that the specific resistance is the same as that of the liquid in mass. It was therefore uncertain whether the physical properties of films of such different thicknesses were the same, and it was necessary to check by some independent method the absolute thicknesses deduced from the electrical experiments. The thickness of a single black film is indeed so small that it is probably impossible to measure it by any direct optical method. We have, however, succeeded in determining optically the average thickness of a number of such films, and have thus obtained the required independent confirmation of the results of the electrical observations.

We propose therefore to describe (1) the electrical, (2) the optical experiments, and finally to compare the results with each other, and with those already referred to which were obtained some years ago.

I. *Electrical experiments.*

The liquid employed in the experiments of which we have already published a description, was invariably PLATEAU's *liquide glycérique*, to which was added 3, 5, or 7 per cent. of potassium nitrate. This liquid is admirable for many purposes. Films made with it are very persistent, thus allowing long continued observations to be made upon them, but they cannot always be depended upon to thin so far as to exhibit the black of the first order. Sometimes the black appears, and extends to a distance of two or three millimetres, or even more; at other times no trace of black is seen after several hours. We have not on any subsequent occasion been able to secure with a *liquide glycérique* a formation of black at all comparable in extent with that obtained in several of the experiments described in our first Paper above referred to. It was necessary for our purpose to discover a liquid from which films could be made possessing the two-fold property of persisting and of becoming black with tolerable regularity. Moreover, the black must extend to a distance of at least 11 millims. from the top, to admit of observations of any value being made upon it by the electrometer method. Experiments extending over many months were carried out with the object of discovering such a liquid, and a number of different solutions were examined, consisting of mixtures of glycerine, water and oleate of soda in varying proportions, potassium nitrate being in all cases added to increase the conductivity. It was found at last that a plain soap solution not containing any glycerine answered the purpose best, and the solution employed in the experiments about to be described had the following composition :—

	Grammes.
Oleate of soda	1·44
Potassium nitrate	2·88
Distilled water	100

Specific resistance.—The specific resistance of the soap solution was determined by the method described in our previous paper (Phil. Trans., *loc. cit.*).

At 12° C the specific resistance was 43·9 ohms per centimetre cube.
15 " " 40·8 " "
18·8 " " 37·0 " "

We may therefore assume without important error the specific resistance at the temperatures :—

	13°	14°	15°	16°	17°	18°
to be	43	42	41	40	39	38

Refractive index.—The refractive index of the solution was 1·337 at the temperature 16° C.

Description of the apparatus.—The apparatus constructed for us by Messrs. ELLIOTT Bros. is represented, half size, in Plate 47, fig. 1. It consists of a box made of thick glass plates, bevelled at the edges, and cemented together. The internal dimensions are 10 centims. square by 16·25 centims. high. The lid is a glass plate 11·4 centims. square, which closes the box airtight by means of a little grease. To it are attached all the essential parts of the apparatus. The lid with its fittings is shown in plan in fig. 3.

The soap film is supported between two platinum cylinders B and F (fig. 1), each 32·5 millims. in diameter. B is screwed to the end of a brass tube A, with a rack running along its length, which passes through a hole in the centre of the lid. It can be raised or lowered by means of a pinion C (figs. 1 and 3). That part of it which extends above the lid is enclosed in a larger tube in such a way that it can be moved up or down without establishing any connexion between the inside of the box and the outer air. D is a brass rod terminating below in a stout platinum wire E, which is bent at right angles and carries the short cylindrical ring F, perforated with holes. The rod D passes through an ebonite sheath G cemented to the lid. H is an ebonite milled head by which the ring F can be moved laterally as well as up and down.

The needles are supported in the following manner :—J is a brass tube accurately fitting the ebonite sheath, K, and terminating in a milled head, L. It supports a rectangular prism of ebonite, through which pass two straight gold wires, the so-called needles. The extremities of the latter are soldered to fine insulated copper wires, which pass through a hole in the tube, seen at N, and are connected at the top of the tube to the binding screws, *c*, *c*. A glass shield, cemented to the ebonite clip P, and perforated with holes through which the needles pass without touching the glass, is employed to protect the pillar which supports the needles from the spray caused by bursting of the films. The tube J can not only be turned about its own axis, but the hole through which the sheath K passes being slotted, as shown at W, fig. 3, can be moved to and fro parallel to itself to a limited extent. By these means the needles can be inserted in the film in any suitable position. Only two needles are represented in the figure. There were three, but as a rule two only were used. *a* and *b* are binding screws for connecting the upper and lower supports of the film respectively with the circuit.

On the left of figs. 1 and 3, and in fig. 2 is shown the arrangement for saturating the inside of the box with moisture. It consists of an endless strip of linen O, passing over an ebonite roller Q, and kept stretched by an ebonite roller R below, the latter being weighted by a core of lead. The frame S carrying the strip can be raised or lowered by means of a nut T working on a screw fastened to the frame, and thus the linen can always be made to touch the liquid with which the bottom of the box is covered. The bevelled wheels seen at U, and the screw-head V, show how the upper roller is rotated so as to bring all parts of the linen in succession in contact with the liquid. The strip becomes elongated when wet, but by the nut T it can be drawn up to a suitable height. All the fittings connected with this part of the apparatus are of ebonite.

The hair hygrometer and the thermometer are not shown in fig. 1. They are supported on a single frame which is attached to the lid at Z, fig. 3. X is a plug closing a hole through which the liquid is introduced into the box.

To ensure constancy of temperature the film-box was placed in the centre of a glass tank full of water at the temperature of the room. The tank is made of thick glass plates, bevelled at the edges and cemented together. It is 30 centims. high by 25 centims. square. In the centre of it is fitted a square glass case of the same height as the tank, open top and bottom, and just large enough in cross section to allow the film-box to slide into it down to a fixed support. When the film-box is in its place it is surrounded by 7·5 centims. of water on every side except top and bottom. It was necessary to leave the top exposed in order to be able readily to move the needles or the linen strip, but the space underneath was filled up with cotton wool. By these means the temperature inside the film case can be maintained constant for many hours together.

The principle of the method of investigation employed was the same as that adopted in our previous experiments. A current from a battery of 9 LECLANCHÉ cells was passed through a film from top to bottom, and also through a box of resistance coils containing a resistance of one megohm. The binding screws forming the terminals of this resistance could be connected with the electrometer. The gold needles could also be connected with the electrometer. Thus the difference of potential between the two needles in the film could be compared with that between two other points in the same circuit separated by a known resistance, and the resistance of the film between the two needles thence determined. The independent difference of potential between the needles, when they were in the film, but when no current was passing, was troublesome, but was reduced to a minimum by carefully cleaning them with nitric acid at the beginning of each day's work. Every part of the circuit was carefully insulated, and the insulation of the two gold needles was specially tested at the end of each set of observations. If the result of the test was not satisfactory, the preceding observations were discarded. In the case of no experiment given below did the insulation-resistance of the needles fall below 300 megohms.

The observations were carried out in the following manner. The glass case having been thoroughly cleaned and the hygrometer adjusted to stand at from 40° to 50° on the scale, when in a saturated space, the cover with its fittings was introduced into its place, and the apparatus thus enclosed was placed in the centre of the glass water-tank. The ebonite plug X, fig. 3, was then removed, a tube terminating in a small funnel introduced, and about 20 centims. of the soap solution poured in. This quantity was sufficient to cover the bottom of the box to a height of about 3 or 4 millims. The tube was withdrawn and the plug replaced. The screw-head V was then rotated so as to bring every part of the endless band into the liquid. This operation was subsequently repeated from time to time to ensure the linen remaining thoroughly wet. The apparatus was then left to itself for 30 or 40 minutes, which interval was as a rule sufficiently long to allow the hygrometric state to become constant. The hygrometer index rose at first rapidly and afterwards more slowly to a limiting position which it steadily maintained. On one occasion the indication was observed at intervals during 36 hours, and did not vary more than a tenth of a scale division. The new apparatus has, in fact, enabled us to overcome the chief difficulties encountered with the old. We can now maintain the temperature and hygrometric state of the space round the film constant as long as we wish. To proceed:—The electrical connexions having been completed, the lower ring F was turned to one side by the button H, and the pinion C rotated until the mouth of the upper cup just touched the liquid. When it was raised, a plane film was formed over its mouth, and this, after the ring F was restored to its position, was blown out into a cylinder in the usual way. The needles were inserted in the film and adjusted so that their position could be easily observed by the cathetometer. The length of the cylindrical film was usually about 34 or 35 millims., and the upper needle was placed about 5 millims. below the cup B. The distance between the points where the needles pierced the film varied in different experiments between 4·6 and 5·3 millims. There were, indeed, as has been stated, three needles on the same support, but only the first and second were used, the third being bent on one side and not touching the films. On one occasion, however, the first and third needles were used, the middle one being bent back.

A mass of liquid having the form of a distorted circle, with its longer axis vertical, formed around each needle at the point where it entered the film. The horizontal wire of the cathetometer telescope was made to touch this circle at the top and bottom, and the mean reading was taken as that proper to the needle. The ratio between the mean diameter of these liquid masses and their distance apart was a necessary datum in applying a correction to the direct results. This correction was necessitated by the fact that the equipotential lines, which in the undisturbed film are horizontal circles, are distorted in the neighbourhood of the liquid masses formed by the insertion of the needles.

If a be the mean radius of these circles of liquid,
b their distance apart,

then calculation shows that the observed resistance of the film between the needles must be increased by the following percentages:—

$$\text{If } \frac{b}{a} = 6, \quad 7, \quad 8, \quad 9, \quad 10$$

$$\text{percentage to be added} = 6{\cdot}1, \; 4{\cdot}3, \; 3{\cdot}4, \; 2{\cdot}6, \; 2{\cdot}2.$$

The films, although they were all made from the same solution and thinned under apparently identical conditions, behaved very differently one from another. Sometimes a ring of black was seen to form a few minutes after the film was blown, and to extend rapidly downwards. At other times half an hour elapsed before any black appeared. The passage of the electric current has a considerable effect in retarding the initial formation of the black, and sometimes prevents it altogether. When the black is once formed, the passage of the current appears sometimes to check its growth, but this effect is not always observed. As a rule the circuit was not completed until the film was in a condition suitable for electrical measurements, or, in other words, until the black had extended to a distance of 1·5 or 2 millims. below the second needle. Few films reached this stage, and we considered ourselves fortunate if in a day's work we succeeded in making trustworthy observations on a single film. If the black reached the second needle it not unfrequently continued to spread far below. On three or four occasions the film became black from top to bottom, a distance of 34 millims. The phenomenon of a cylindrical soap film, 32·5 millims. in diameter and 34 millims. long, black throughout its entire area, is a very remarkable one. Under these circumstances, so little light is reflected from any part of the film, that it is difficult to say at first sight whether a film is present or not.

The following table (Table I.) contains the results of our observations of 13 films. No results have been omitted from the table excepting such as we knew to be affected with error owing to defective insulation of the needles or other causes.

TABLE I.

Date and number of film.	Tempera-ture.	Distance between needles. (b)	Mean radius of liquid mass round each needle. (a)	Number of observations from which the result is derived.	Length of *black* when film broke.	Time the film lasted.	Time occupied in electrical observations.	Resistance of black (ohms per millim.).	Per-centage to be added.	Resistance corrected for disturbance of equipotential lines.†	Resistance of liquid in mass at temperature of observation (ohms per c.c.).	Thickness of black (10^{-6} millims.).
	°	millims.	millim.		millims.	minutes.	minutes.					
1882.												
Dec. 21, III.	14·5	4·95	0·6*	6	14	35	15	320,600	3·0	330,200	41·5	12·31
„ 26, III.	14·2	4·82	0·6*	8	27	..	..	299,000	3·4	309,200	42·0	13·30
„ 26, IV.	14·5	4·65	0·6*	5	Throughout	..	..	294,000	3·6	304,600	41·5	13·34
„ 26, V.	14·8	4·625	0·6*	12	Throughout	..	..	297,000	3·6	307,700	41·2	13·11
„ 27, IV.	15·6	10·13	..	5	30	..	..	273,000	..	273,000	40·4	14·49
1883.												
Jan. 8, I.	14·4	5·42	0·59	1	15	25	3	317,000	2·5	324,920	41·6	12·54
„ 8, II.	14·7	4·85	0·55	5	20	53	11	504,000	2·8	518,100	41·3	7·81
„ 8, III.	14·8	4·85	0·56	10	Throughout	75	30	546,000	2·9	561,800	41·2	7·18
„ 10, VI.	14·0	4·625	0·65	5	Throughout	73	18	368,000	4·2	383,500	42·0	10·73
„ 20, VII.	16·1	4·815	0·53	4	30	48	18	316,000	2·6	324,200	39·9	12·05
„ 20, VIII.	16·3	4·84	0·63	6	33	50	28	340,900	3·7	353,500	39·7	11·00
Feb. 8, II.	14·8	5·30	0·62	6	13	90	20	319,000	3·0	328,600	41·2	12·28
„ 8, III.	15·0	5·32	0·70	11	29	180	120	310,700	3·7	322,200	41·0	12·47
											Total . .	152·61
											Mean . .	11·74

* Approximately; the diameter was not accurately measured.

† The correction is only carried to four significant figures.

Our observations show that the black, at least in a cylindrical film, does not become thinner by lapse of time or by increase of area. In illustration of this point we may refer to Film III., Jan. 8, and Film III., Feb. 8.

Film III., Jan. 8.—The measurements began when the length of the black portion was about 11 millims., and were continued until the whole area of the film was black. The first measurement was made 45 minutes after the film was formed.

The resistance of the film between the needles

50 minutes after the film was formed was	2·63 megohms
60 " " "	2·69 "
72 " " "	2·67 "

The mean of all the observations was 2·672.

Film III., Feb. 8.—This film, after being formed, was left to itself for an hour. At the end of this time about 15 millims. were black, and observations were at once commenced and were continued at intervals during two hours, at the end of which the film burst. The extreme length of the black was 29 millims.

After $1^h\ 20^m$ the resistance was	1·644
$2^h\ 20^m$ " "	1·607
$2^h\ 50^m$ " "	1·680

The mean being 1·654.

Although in any given film the thickness of the black appears to be fairly constant, it will be seen from the above table that the thicknesses vary a good deal in different films. The most serious deviations from the mean occurred on Jan. 8 in Films II. and III., the values deduced from these being 7·82 and 7·19. We have no reason however to think the experiments on this day less trustworthy than others, as none of the precautions usually taken to ensure accuracy were neglected. Defective insulation at the needles, involving a deviation of the circuit, would have resulted in an increased and not a diminished value of the thickness. The fact that Film I. of the same date yielded the value 12·53, which does not differ much from the mean of the others, precluded the possibility that a different liquid had by some mischance been used. The number 12·53, however, had been derived from a single observation, and hence might appear to be less trustworthy than the others. To set all doubt on this point at rest, the specific resistance of the liquid used was without delay redetermined, and was, as was expected, found to be normal.

II. *Optical experiments.*

The object of these experiments was, as has been already stated, the measurement of the mean thickness of a number of black soap films by an optical method.

A **Fresnel's** optical bank, of the pattern devised by Professor **Clifton**, was fitted with the apparatus necessary to produce interference bands by means of thick plates. The plates were specially prepared by Messrs. **Elliott** Bros., and as their thickness was 18 millims., a considerable separation of the two interfering rays could be obtained. The angle between the two plates of the compensator could be altered, so that the sensitiveness of the instrument was under control and the angular motion of the whole compensator could be read off correct to 1′ by means of a vernier. A small brass table was placed between the mirrors. It was carried by one of the sliders of the bank, and could be raised or lowered by rackwork. To this a brass plate, 460 millims. long by 50 millims. broad and about 3 millims. thick, was firmly clamped. It was furnished with two pairs of brass V-pieces, in which glass tubes about 400 millims. long and 18 millims. in internal diameter were placed. The ends of the tubes were ground and closed with plates cut from the same piece of plate glass. The requisite adhesion between the plates and tubes was obtained by slightly moistening the extremities of the latter.

All the different parts of the apparatus were marked, so that after each readjustment they could be readily replaced in the positions they previously occupied. With this precaution it was possible to remove the tubes and set them up again many times in succession without displacing the interference bands from the field of view.

The light employed was that of an oil lamp, and to prevent disturbance by heat from this, the apparatus was set up in front of a draught closet within which the lamp was placed. The window was then closed and the air surrounding the apparatus was thus completely cut off from that in the neighbourhood of the flame. A large screen of stout pasteboard prevented any light or radiant heat from the lamp or from the window of the draught closet falling upon any part of the apparatus except the first mirror and its immediate surroundings.

Before performing an experiment the interiors of the tubes were thoroughly moistened with the liquid to be used, into which one of the extremities of each of them was then dipped. On withdrawing them plane films were formed in the tubes, which, if they were then inverted, ran a little way down them. A second film could then be formed in each by again dipping the ends in the liquid, and so on until the tubes contained between 50 and 60 films apiece. Being thus charged they were placed in the V-pieces, closed with the glass plates, and left undisturbed until the films had thinned sufficiently to make an observation possible.

During the whole of this process, each film, with the exception of the first and last formed, was only directly exposed to the air for the few seconds which elapsed before the next in order was made. A considerable quantity of liquid was retained between the films, so that when the tubes were closed by the glass plates the whole of the air within them must speedily have become saturated. In this saturated space the films remained for at least half an hour if formed of plain soap solution, or at least an hour if formed of *liquide glycérique* before they were ready for observation. The constitution of the films therefore cannot possibly have differed much from that of the liquids from which they were formed, and even if this were not so the changes in the refractive indices would have been too small to produce appreciable errors (see Phil. Trans., 1881, p. 485). When the films were thinning the field of view was traversed both by bands of colour due to the interference produced by the thin films, and by others due to the thick plates. To prevent confusion we propose to restrict the term interference *bands* to the first of these, and to call the second *fringes*. The instrument was so adjusted that the fringes were vertical and widely separated. Cross wires were introduced into the middle of the field of view, the compensator was placed in the vertical position and the central black fringe, exhibited when white light was used, was brought up to the vertical wire by slightly altering the orientation of the mirrors. A sheet of ruby glass was then interposed between the lamp and the mirrors, and the angles through which it was necessary to turn the compensator, to bring up to the vertical wire the fringes which were right and left of the central one, were measured. The mean of these values was taken as the angle corresponding to a wave length of red light, or according to our previous measurements to 615×10^{-6} millims. (Phil. Trans., 1881, p. 454).

The red glass having been removed, the "zero" or reading of the compensator when the central black fringe touched the vertical at its intersection with the horizontal cross wire was determined. It was then necessary to break a number of films in one of the tubes without in the least shaking or disturbing the apparatus. For this purpose one or two stout sewing needles had been enclosed with the films. A strong electromagnet was now used to move these, and a known number of films having thus been broken, the displacement of the black line was determined. In breaking the films care was always taken to leave if possible two or three unbroken at each end of the tube. Disturbance by the irruption of air from the outside, if the contact between the ends of the tubes and the glass plates was imperfect, was thus prevented.

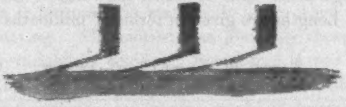
If then

T be the average thickness of a film,
n the number of films broken,
μ the refractive index of the liquid,
λ the wave-length of red light,
δ the angular displacement of the compensator necessary to restore the central fringe, after the rupture of the films, to the position it previously occupied; and
α the angle (as above defined) corresponding to a wave-length of red light,

we have the equation

$$n(\mu-1)\mathrm{T}=\frac{\delta}{\alpha}\lambda.$$

When the tubes were placed in position the colours of the bright transmitted bands were, owing to the large number of films, very vivid, and the dark bands were very obscure. The fringes which had previously been made vertical were seen crossing the bright bands in a more or less sloping direction, but were completely lost in the darker portions of the field. When the films had thinned sufficiently to show by reflected light the white and black of the first order, the passage from the one tint to the other was, as is usual, so sudden as to appear discontinuous. The corresponding dark and light transmitted bands were very intense and the boundary between them was also perfectly definite and sharp. The fringes visible in the bright portion of the field (corresponding to the black seen by reflected light) were for the greatest part of their length vertical, but at first they often displayed a very considerable curvature at their lower extremities. In such cases they crossed the boundary at a very small angle and were lost in the dark band. The direction of the curvature was different on different occasions. The accompanying figure is a reproduction of a sketch on an



enlarged scale made at a time when the phenomenon was very marked. The cause of the curvature was evidently an increasing difference of thickness between the films in the two tubes in the neighbourhood of the limits of their black portions.

As all did not thin at precisely the same rate, this limit was in different films at different vertical elevations, and it might at first sight seem probable that the curvature was due to the fact that the boundaries between the white and black were in the one tube lower than in the other. The interfering rays in a given horizontal plane would thus, in the one case, traverse black films only, while in the other they would also pass through some white ones, and, as the number of these would increase rapidly as the vertical elevation of the plane diminished, a distortion of the fringes similar to that observed might have been produced.

If this had been the true explanation, we should have expected either that the intensity of the illumination would have increased gradually on passing from the dark to the bright transmitted bands, or that a marked discontinuity would have been observed in the curved fringes at the points where the number of the white films traversed increased. Neither of these phenomena were observed. The dark part of the field was very intense close to the boundary and the curves were unbroken.

Another hypothesis which would serve to explain the phenomenon is that the black portions of the films increased in thickness near the junction with the white, and that this increase was different in the two tubes. No evidence of any such change of thickness was ever given by the electrical experiments, but it is, of course, possible that the behaviour of the cylindrical and plane films might in this respect be different.

Let n and n' be the number of the films in the two tubes. Let the mean thicknesses of the films in the first tube at the levels where the fringes crossed the boundary into the dark (transmitted) band, and where they became vertical, be t_1 and t_2, and in the second let them be t_1' and t_2'. Then the difference of the paths of the interfering rays would be

$$\{(nt_1-n't_1')-(nt_2-n't_2')\}(\mu-1)=\frac{\delta}{\alpha}\lambda$$

where δ is the angular displacement of the compensator corresponding to the distance between the centre of one of the vertical fringes and the point where it cuts the boundary. Now since t_1 and t_1' are greater than t_2 and t_2' respectively, $\lambda\delta/(\mu-1)n\alpha$ is an inferior limit of the quantity t_1-t_2.

The following table gives the data by which the value of this limit was determined on several occasions. Lengths are given in terms of millionths of a millimetre.

TABLE II.—$\lambda=615$, $\mu-1=0{\cdot}4$.

δ/α.	n.	t_1-t_2.
1·26	36	53·8
0·75	49	23·5
0·92	31	45·6
0·84	58	22·2

This table shows that a very considerable change of thickness is necessary to account for the phenomenon. If the average thickness of a black film be taken as 12×10^{-6} millims., the films in one tube at the boundary of the black must have been from 3 to 5 times as thick as elsewhere.

This explanation is not without its difficulties. The thickness of the "beginning of the black," when the proper correction for the refractive index is made, is, according to NEWTON'S tables, 36×10^{-6} millims., whereas one of our experiments (if we adopt the above hypothesis) shows the average thickness of the thickest black parts of the film to be $(53{\cdot}8+12)\times10^{-6}=65{\cdot}8\times10^{-6}$ millims.

This discrepancy may, perhaps, be explained by the fact we have already referred to (Phil. Trans., 1881, p. 453) that measures on the diameters of NEWTON'S rings are of little value near the central black patch.

It is, however, difficult to understand why all the films in one tube should behave so differently from those in the other, while, if it be assumed that the difference is caused by a few films only, it becomes necessary to extend the limits of the black through an improbable range. The phenomenon was always transient, and the whole of the curvature took place within a distance of one or two millimetres.

The measurement of the shift of the zero was a matter of some nicety. The field of view was scarcely large enough to make it convenient to take the readings when the vertical wire bisected the interval between two dark fringes. The observations were therefore made by causing them to touch the vertical cross wire, and, as their outline was irregular, it required some care to decide upon the particular phenomenon which should be called contact. Two readings might easily differ by a degree or more, *i.e.*, by from $\frac{1}{13}$th to $\frac{1}{14}$th of a wave length. As a rule the errors were much less, and the mean of five readings was always taken. Another reading as large or as small as the largest or smallest would hardly ever have altered the mean by more than 6′, and we think the extreme possible error of the mean is not more than 10′. The most serious difficulty was due to the instability of the zero. The two tubes were mounted, as has been described, side by side, and the distance travelled by the interfering rays in unenclosed air was not more than 30 centims. Owing, however, either to slight changes in temperature or hygrometric state, or to some other undetected cause, the zero was continually moving. The motion was generally though not always in one direction. It was very variable in amount. Sometimes it was negligible, sometimes it produced a change of 4° or 5° in as many minutes. It is evident that the thickness of the films, given by any particular experiment, would be greater or less than the true value according as the motion of the zero was, or was not, in the same direction as that produced by the rupture of the films. The observed facts were in accordance with this, and the numbers obtained were generally larger or smaller than the mean according to the direction of the motion of the zero before the experiment. If therefore the motion remained constant during observations made on the two tubes, the results given by each would be oppositely affected, and the mean value would be correct. Even if, as was the case, it was impossible to ensure such constancy, the error of the mean would probably be much less than that of the individual observations. In all our experiments, therefore, the result of each was taken to be the mean of the numbers obtained by breaking the films first in one tube, and then in the other.

The following are the details of the last experiment performed with the *liquide glycérique*. The zero was on this occasion remarkably steady.

The ruby glass having been placed in front of the lamp, the angles through which it was necessary to turn the compensator to bring the fringes to the right and left of the central dark fringe into the position it previously occupied, were measured. These were always taken in the order—centre, left, centre, right, centre. The readings right and left were compared with the means of the two readings for the centre between which they were taken, to reduce the effect of any zero movement which might be in progress.

The angles given by two such sets of measures were

13° 41′, 13° 31′, 13° 25′, and 13° 59′; mean 13° 39′.

The ruby glass was then removed and the experiment proceeded with as follows:—

Films counted.—Tube I., 59. II., 53.

Position of zero.—Five readings, when the central black fringe was in the standard position, gave

$$1^\circ\ 50',\ 1^\circ\ 58',\ 1^\circ\ 46',\ 1^\circ\ 45',\ \text{and}\ 2^\circ\ 13'\ \text{respectively.}$$

Films counted again.—Tube I., 58. II., 53.

Position of zero read once more 1° 37′.

Mean of six readings 1° 52′.

Films broken in Tube I., then counted

Tube I., 4. II., 53.

New position of zero determined five times

$$6^\circ\ 42',\ 6^\circ\ 11',\ 6^\circ\ 58',\ 7^\circ\ 12',\ 7^\circ\ 15 .$$

Films counted and found unaltered.

Position of zero read once more 7° 10′.

Mean of six readings 6° 55′.

Films broken in Tube II.—A slight delay occurred here, as some of the films did not break easily. When the operation was completed they were counted again

Tube I., 4. II., 4.

New position of zero determined five times

$$3^\circ\ 26',\ 3^\circ\ 24',\ 3^\circ\ 2',\ 3^\circ\ 18',\ 3^\circ\ 26'.$$

Mean of five readings 3° 19′.

Hence the zero shifted $6^\circ\ 55' - 1^\circ\ 52' = 5^\circ\ 3' = 303'$ when 54 films were broken in Tube I., and $6^\circ\ 55' - 3^\circ\ 19' = 3^\circ\ 36' = 216'$ when 49 films were broken in Tube II.

As therefore $\alpha = 13^\circ\ 39' = 819'$, and $T = \delta\lambda/\alpha n(\mu - 1)$ we get from the first tube (in millionths of a millimetre)

$$T = 303 \times 615/819 \times 54 \times 0{\cdot}4 = 10{\cdot}5,$$

and from the second

$$T = 216 \times 615/819 \times 49 \times 0{\cdot}4 = 8{\cdot}3.$$

Mean value $T = 9{\cdot}4$.

This result is less than usual. During the experiments on the first tube the zero was very steady, and the value obtained was almost exactly equal to the mean from all the experiments. Before the observations on the second tube, the zero showed a tendency to rise, and the slight delay which followed may have given time for a motion sufficient to reduce the second value to that actually found.

The following tables give the results of the experiments.

The films formed of plain soap solution did not last so well as those made of *liquide glycérique*. The numbers broken in the experiments are therefore smaller. Several experiments failed, as too many films broke before they were ready for observation, or, as some slight disarrangement of the apparatus was observed, which would invalidate the observations.

Two observations on the soap solutions gave results so widely different from the rest that they are omitted as probably incorrect. With these exceptions all the results obtained are included in the tables.

Column I. gives the number of minutes which elapsed after the tubes were set up, before the films were broken in tubes 1 and 2 respectively.

Column II. gives the number of films broken in each tube.

Column III. the average thickness of a film in millionths of a millimetre.

Table III.—Soap Solution.

I.		II.		III.
1.	2.	1.	2.	
40	50	21	30	14·4
30	40	32	46	11·7
160	180	34	29	11·9
30	35	23	26	11·4
90	95	36	33	10·6
37	40	17½*	18½*	11·8
35	45	17	13	13·2†
33	40	24	20	10·3†
33	40	34½*	32	13·4
				Mean 12·1

Table IV.—Liquide Glycérique.

I.		II.		III.
1.	2.	1.	2.	
87	93	35½*	31	10·6
85	93	27	30	10·2
80	85	28	32	12·5
60	63	52	51	10·7
65	70	50	49	10·2
75	82	49	45	11·0
65	63	54	49	9·4
				Mean 10·7

It will be observed that there is no relation between the time which had elapsed since the formation of the films and their thickness.

* Films broke during measurements.

† Zero very unsteady.

III. *Summary of results.*

We are now able to sum up the results of our experiments. Observations have been made upon three liquids, the properties of which are given in the following table.

Date of observation.	Nature of liquid.	Percentage of KNO_3 in water of solution.	Refractive index.	Specific resistance at 15°.
1877	Liquide glycérique	3	1·395	214
1883	"	5	1·397	166
"	Soap solution without glycerine .	2·88	1·337	41

The first and third liquids were examined electrically; the former by the galvanometer, the latter by the electrometer method. The second and third liquids were examined by the optical method.

In no case was there any evidence, when the liquid films were cylindrical, of a change in the thickness of the black portion. In the case of the plane films formed in the tube, the optical observations indicated an increase in the thickness of the black near its lower extremity. The evidence on this head is however doubtful. Whenever the area of the black portion of the film became somewhat extended the phenomenon, which may indicate a difference between the thicknesses of its various parts, disappeared. There seems, therefore, no doubt that in the case of films formed as in our experiments, the black portions assume a particular thickness either at, or soon after, their first formation, and that this remains unaltered either by lapse of time or by alterations in the dimensions of the black area.

Although, however, our observations prove that this thickness is practically constant for any one film, they indicate considerable variations in its magnitude for different films. The differences between the numbers given by the optical method are perhaps not much in excess of the probable error of experiment, but in the case of the electrical observations they far exceed it. They may be partly due to slight changes in constitution; but the following reasons negative the supposition that this is the only, or indeed an important, cause.

In the first place, the constitution of a *liquide glycérique* is more difficult to maintain unaltered than that of a soap solution. It is, however, in films formed with the latter that the greatest apparent variations in thickness occur. This, on the other hand, is in accord with the fact that films formed without glycerine are, as is proved by the colour phenomena they display, more uncertain and irregular in their behaviour than those made of the standard solution. Again, if a change of constitution took place, we should probably have detected it by progressive changes in the calculated thickness, which would in reality have been due to alterations in the specific resistance. Finally, the absolute constancy of the hygrometer and thermometer seem to preclude the possibility of any considerable change of constitution even in a black film. On the whole then we think that the thickness of the black portions is really different in different films. These differences are in general relatively small. According to **Newton**, the thickness of the "beginning of the black" would be 36×10^{-6} and 37×10^{-6} millims. for the *liquide glycérique* and the soap solution respectively. Apart, therefore, from our previous knowledge of molecular magnitudes, any thickness less than these would be equally probable; but the following table of the results obtained proves that both methods concur in showing that the average thickness is about $11{\cdot}6\times10^{-6}$ millims., while the electrical experiments show that the "probable error," or divergence of the thickness of any given film from the mean value, is $1{\cdot}2\times10^{-6}$ millims.

TABLE V.

Liquide glycérique.		Soap solution.	
Electrical method (1877).	Optical method (1883).	Electrical method.	Optical method.
12·2	10·6	12·32	14·4
11·9	10·2	13·32	11·7
12·0	12·5	13·36	11·9
11·6	10·7	13·13	11·4
12·0	10·2	14·46	10·6
..	11·0	12·58	11·8
..	9·4	7·82	13·2
..	..	7·19	10·3
..	..	10·74	13·4
..	..	12·07	..
..	..	11·01	..
..	..	12·29	..
..	..	12·46	..
Mean 11·9	10·7	11·74	12·1

Into the causes of the variations in the thickness of different black films we do not now propose to enquire. The above observations prove that they are comparatively small. The fact that the boundary between the black and coloured portions of a film is always well defined, and that there must therefore be a very sudden change of thickness in passing from the one to the other seems to point to a region of instability in the neighbourhood of the beginning of the black, such that films, the thicknesses of which are included within it, thin very rapidly to below its lower limit. Very short-lived films made of ordinary soap and water sometimes exhibit a grey tint, intermediate to the white and black of the first order, but persistent films, as far as our experience goes, never do. The foregoing observations seem to fix the limit of this region at about $14\cdot5 \times 10^{-6}$ millims., and to prove that films generally thin to below but not to very much below it, so that the thickness of black soap films rarely differs from $11\cdot6 \times 10^{-6}$ millims., by more than one or two millionths of a millimetre. It has never been observed to fall below $7\cdot2 \times 10^{-6}$ millims., and thus, without attaching any theoretical importance to the term, this thickness seems to be practically the *limiting thickness* of such liquid films as we have studied.

We conclude by summarizing the results arrived at in this and our former papers with respect to black soap films :

(1.) Persistent soap films, which thin sufficiently to exhibit the black of the first order of NEWTON'S rings, invariably display an apparent discontinuity in their thickness at the boundary of the black and coloured portions.

(2.) The whole of the black region at the time of or very soon after its formation is of a uniform thickness.

(3.) This thickness remains unaltered in any film, whether the coloured parts of the film are thinning or thickening, increasing or diminishing in extent.

(4). It is different for different films, but no connexion has been traced between its magnitude and the time which elapsed between the first formation of the film, and the first appearance of the black, or between either and the time of observation.

(5.) The mean values of this thickness are the same to within a fraction of a millionth of a millimetre, whether the films be plane or cylindrical, in contact with metal or with glass, formed of soap solution alone or with the addition of more than two-thirds of its volume of glycerine.

(6.) Two completely independent methods of measuring the thickness of the black portions of the films give concordant results.

(7.) The mean value of the thickness, calculated by giving equal weight to the results of the electrical and optical experiments, is $11\cdot6 \times 10^{-6}$ millims., the extreme values being $7\cdot2 \times 10^{-6}$ and $14\cdot5 \times 10^{-6}$ millims.

The smaller of these quantities is therefore a limiting thickness to which a soap film in air saturated with the vapour of the liquid from which it is formed rarely attains, and below which none of the films observed by us have thinned.

XXI. *The Direct Influence of Gradual Variations of Temperature upon the Rate of Beat of the Dog's Heart.*

By H. Newell Martin, *M.A., M.D., D.Sc.; Professor in the Johns Hopkins University, Baltimore, U.S.A.*

Communicated by Dr. M. Foster, *Sec. R.S.*

Received December 27, 1882,—Read January 11, 1883.

[Plates 48, 49.]

Introduction.

In the year 1881 I briefly described (1) a method of experimenting by which the heart and lungs of a Dog or Cat could be completely isolated physiologically from the remainder of the body of the animal, and kept alive some hours for study in an apparently normal condition, the heart beating regularly and maintaining a good arterial pressure. Since then I have been at work investigating the influence of various conditions upon the pulse-rate of Dogs' hearts so isolated; while under my supervision several of my pupils have been engaged in studying the work done in a unit of time by such hearts under different external conditions.

As regards the effects of variations of arterial pressure upon the pulse-rate of the isolated Dog's heart, my results have already been published (2); and detailed observations as to the influence of variations in venous pressure will shortly be printed. But in so far as the influence of temperature variations upon the cardiac rhythm is concerned, only a brief preliminary announcement (3) has been made. In the present paper I propose to give a full account of my experiments upon this subject, which is one that, apart from and in addition to its purely physiological interest, has considerable practical importance in connexion with inquiries as to the immediate cause of the quick pulse so constantly found in warm-blooded animals suffering from fever.

Almost all that we have hitherto known concerning the direct influence of temperature changes upon the cardiac rhythm is derived from experiments made upon cold-blooded animals, especially Frogs. As regards these animals all observers are agreed that as the temperature of the heart is gradually raised from near zero to about 40° C., its beat is quickened. It is clear, however, that we can only argue with much reserve from the heart of the Frog to that of the Mammal when the direct effect of temperature variations is concerned. The Frog can hardly be said to have any normal temperature, and has but slightly developed temperature-regulating physiological mechanisms; its healthy temperature varies from a very low point in midwinter to 32° C. or above on a Baltimore summer day. The Mammal, on the contrary, is constructed to maintain a definite normal temperature, which does not vary beyond very narrow limits; a departure of even a couple of degrees from this normal is always the sign or the cause of pathological processes. We find the Mammalia, accordingly, provided with highly complex temperature-regulating mechanisms, in possessing which they differ very sharply from the Amphibia. While it might therefore be expected *à priori* that the Frog's heart is so constructed as to work better at those warm temperatures at which the general nervo-muscular apparatus of the animal is most active, and the calls upon the organs of nutrition greatest, the discovery that such is actually the case and that the warmed hearts of Frogs beat quicker than cold, does not justify us in forthwith concluding that the Mammalian heart, placed in and adapted to the needs of an animal with only one healthy temperature, would behave in like manner. This doubt concerning the validity when extended to warm-blooded animals of arguments based on experiments made with the hearts of Frogs is increased when we call to mind the fact that an elevation, within physiological limits, of the temperature of the medium to which a cold-blooded animal is exposed increases its tissue metamorphoses, as evidenced by a greater excretion of carbon oxide, while exactly the reverse is the case in respect to the Mammal. Recalling the wonderful physiological adaptation of the organs of animals to the conditions under which they live, we might almost expect that increased temperature (not reaching pathological limits) of the blood carried to it would lead to a slowing of the beat of the Mammalian heart in correlation with the diminished oxidations then occurring in the body generally, and its consequently diminished nutritional demands.

There are still other reasons why the direct application to the Mammalian heart of the results of experiments upon Frogs is unsatisfactory. It has been shown (4) that the muscular tissue of the Amphibian heart differs considerably in histological characters from that of the Mammalian: with this difference in minute structure quite important functional differences may be associated. Moreover, the Mammalian heart is known to be far more under the control of extrinsic nerve centres than is that of the Frog. Though the heart of the latter animal receives cardio-inhibitory fibres through the vagus, their centre of origin is not usually in action, as shown by the fact that cutting the vagi does not lead to pulse-quickening; exactly the reverse and to a very marked extent is the case in the Dog (see especially V. BEZOLD) (5), and also in Man as shown by the phenomena observed in cases of atropin poisoning. In addition, the Mammalian heart receives from the cerebro-spinal centre accelerator nerve fibres, and the existence of any such pulse-quickening fibres in connexion with the Frog's heart is at present doubtful. Consequently, bearing in mind that greater division of physiological duties which characterises the higher animal, we may justifiably doubt whether the simple relation of higher temperature (within limits) and quicker pulse found in the Frog and dependent only on the properties of the heart itself, may not be entirely absent in the isolated heart of the higher animal, which we know to have its rate of beat under normal circumstances controlled by a highly specialised set of extrinsic nerve centres.

The above considerations, taken in connexion with the fact that "fever" can hardly be said to exist in an animal with so variable a normal temperature as the Frog exhibits, made it very desirable to study directly the influence of temperature variations upon the pulse-rate of the Mammalian heart.

The experiments hitherto made upon Mammalia do not really solve the question whether the quicker pulse of the warmer animal is due to a direct or an indirect action (*i.e.*, one exerted by extrinsic nerve centres) upon the heart. **BERNARD**, **WALTHER**, **HORWATH**, and no doubt others have found a slow pulse in artificially cooled animals; the same phenomenon has been observed in hybernating Mammals during their winter sleep. As regards the effect of heightened temperature upon the pulse-rate, **BRUNTON** (6) has showed that when Rabbits are heated the heart beats quicker. But when a whole animal is warmed or cooled we are not justified in concluding that because the heart beats quicker or slower therefore the temperature change has directly influenced the rhythm of that organ. Not only may temperature changes indirectly affect the heart through its extrinsic nerves, but they may also so alter tissue metamorphosis in various organs as to essentially modify the composition of the blood flowing through the heart; and we know that very slight alterations in the chemical composition of that liquid may profoundly influence the heart. Before we are entitled to state positively that changes of temperature directly influence the rhythm of the heart of the warm-blooded animal, we must have data based on experiments made with the hearts of such animals cut off from all possible control through extrinsic nerve centres, and supplied with nutriment of constant composition. The only experiments known to me which approach the fulfilment of such conditions are those made by several observers (**SCHENK** (7), **WERNICKE** (8), **CLELAND** (9)) on the influence of temperature changes upon the rate of pulsation of the hearts of embryo Chicks during the first three days of incubation. Such experiments afford, however, even a less safe ground for conclusions as to the adult Mammalian heart than do the experiments upon Frogs' hearts above referred to. The heart of three-day Chick embryos is but a protoplasmic mass, little differentiated, presenting neither definite muscular or nervous tissue, and without any developed controlling extrinsic nerves. From the fact that such a mass of hardly-differentiated embryonic cells contracts more frequently when warm than when cold, we cannot safely conclude that the adult heart, with its fully developed muscular and nervous tissues, and placed under the governance of nerve centres located outside it in the body, would, if isolated, respond in like manner to similar temperature changes.

While experiment upon the isolated hearts of Frogs, Fishes, and Bird embryos, combined with the changes in the pulse-rate observed when Mammals are heated or cooled, have led to a general consensus of opinion among physiologists that gradual and moderate increases of temperature quicken the Mammalian pulse by direct action upon the cardiac tissues, and moderate diminutions of temperature similarly slow the pulse, the proof that the action of such temperature changes was exerted directly upon the heart itself did not seem satisfactory, for the reasons above stated. Hence the investigation described in the following pages was undertaken.

The method.

The fundamental idea upon which all my work on the isolated Mammalian heart has been based is to occlude all vessels of the systemic circulation except those supplying the heart itself, while leaving the pulmonary circulation intact. The heart and lungs being supplied with blood alone retain their vitality; all extraneous nerve centres getting no blood soon die with the remainder of the animal. Moreover, the blood supplied to the heart passes through no organ of the body but the lungs, and in these it undergoes simple and well understood changes; no sudden chemical alteration in it due to the products of the abnormal activity or commencing death of muscle, gland, or brain is possible. As the blood flows around through heart and lungs time and again, it no doubt experiences a gradual deterioration due to loss of foods and gain of wastes from those organs; but this change is gradual and uniform, and if a sufficient quantity of blood be used, the accumulation of wastes (carbon dioxide being carried off by the lungs as in normal conditions) and the deterioration in nutritive quality do not for some hours alter its constitution to an extent which in any way interferes with the forcible, regular, and normal beat of the heart. The means adopted for renewing the blood circulating through heart and lungs, as also for maintaining constant arterial and venous pressures and for regulating the temperature of the blood not having as yet been published in detail, and the method also having been much modified since the preliminary account was published, it is necessary to describe with some minuteness the operation of isolating the heart and the apparatus employed for subsequently keeping it alive under approximately normal and readily controllable conditions. I do this the more readily as the present form of the apparatus is the result of more than a year's experience and the accumulated improvements suggested by several workers (among whom special acknowledgment is due to my friends and pupils W. H. Howell and F. Donaldson), so that it now leaves little to be desired in the convenience with which it admits of keeping a heart under conditions in which venous pressure, arterial pressure, and temperature are readily ascertained and controlled. So far as the present series of experiments (those relating to the effect of temperature changes upon the pulse-rate of the isolated heart) is concerned, Dogs only have been used, and defibrinated strained Calf's blood has been the medium employed to nourish the isolated heart.

The animal having been placed under the influence of chloroform, ether, morphia, or curaré, the further course of an experiment was as follows :—

After tracheotomy the pneumogastro-sympathetic trunks were divided on each side of the neck with the object of saving the heart from the results of the powerful excitation of the cardio-inhibitory centre in the medulla oblongata, which usually occurs later, when the blood-supply of the brain is cut off. A cannula was also placed in the cardiac end of each common carotid artery, the arteries being clamped on the cardiac sides of the cannulæ. Next, the first pair of costal cartilages and the bit of sternum lying between them were cut away, and artificial respiration commenced; then the internal mammary arteries were tied as they pass forwards from the subclavians to the breast bone. The whole front and sides of the thorax were next cut away, and the right subclavian artery dissected out and tied just above the point at which it separates from theright carotid. The superior vena cava was then prepared, and ligatures placed loosely around it ready for subsequently occluding the vessel and tying in a cannula.

Proceeding now to the left side of the chest, the subclavian artery is ligated, and, the left lung being gently held aside, the aorta is isolated and cleared near the diaphragm. A ligature is placed loosely around the vessel, just beyond its arch, and a strong clamp tightened on it to the distal side of this ligature. An aperture having been made in the thoracic aorta, near its posterior end, a cannula of the form represented in Plate 48, fig. 4, and filled with defibrinated strained Calf's blood, is inserted into the vessel, and, the aortic clamp being removed, is pushed up to the left end of the aortic arch, where the ligature above-mentioned is tied tightly around it. These aortic cannulas are made of thin brass tubing, and are kept at hand of several sizes, so that one can always be found which fits tightly into the aorta of the animal, and is closely clasped by the elastic walls of that vessel. The cannula has on its distal end the bit of rubber tubing, *v*, on which is the clamp, *w*, which is screwed tight when the tube is filled with defibrinated blood before its insertion into the artery.

So far all the systemic arteries but the coronaries of the heart are occluded. Each common carotid has a cannula in it; both subclavians are ligated below the point at which they give off any branch, and the aortic cannula is tied in at a level of the vessel, just beyond its arch, at which it has given off no bronchial or intercostal branches.* As one consequence, violent dyspnœic symptoms usually occur in spite of the steadily maintained artificial respiration, being of course due to the want of a supply of fresh blood to the respiratory nerve centre. To complete the preliminary operation the inferior vena cava is tied above the diaphragm, and the right lung being pushed towards the median line, the vena azygos is ligated near its junction with the superior cava; the latter vessel is then tied below the point where the innominate and internal mammary veins join it by tightening one of the ligatures already described as placed loosely around it.

---

* Sometimes in young Dogs a minute branch is given off from the innominate artery to the thymus. This was sometimes tied, but usually neglected, as it is difficult to get at, and the amount of blood drained off by it is trivial, and when both venæ cavæ are tied cannot get back to the heart.

The next step is to wash out the blood contained in the heart and lungs, and replace it by defibrinated blood. For this purpose the cannula *z* (Plate 48, fig. 3), connected with the MARIOTTE flask U, filled with defibrinated Calf's blood at the temperature 38° C., is inserted into the cardiac end of the superior cava, and tied there. The clamp on the tubing connecting the flask with the cannula is opened, and blood from the flask allowed to enter the right auricle. The clamps on each carotid, and on the aortic cannula, are then opened in turn for a short time so as to wash out all blood already in heart and lungs, and replace it with the defibrinated blood.

This having been done, and the clamps again closed, the animal, still tied on the dog-holder, is transferred to the warm moist chamber represented in outline in Plate 48, fig. 1; in this chamber it is thenceforth fed steadily with defibrinated blood of known temperature, supplied at a known and controllable pressure, and from the chamber it pumps out blood against a known and readily varied aortic resistance. The structure, contents, and preliminary preparation of the warm chamber have next to be described. It is 125 centims. long, 65 centims. wide, and 65 centims. high. It has no bottom, but when in use sits in a shallow iron trough (not represented in the figure) filled with water, and raised on supports which admit of BUNSEN burners being placed under it, by whose means the air in the chest is kept moist and warm. The roof, sides, and the end, A, are glazed; the end, B, is of wood, and perforated by apertures through which several tubes pass. The object of glazing most of the walls of the chamber is to enable a ready view to be had of what is going on inside it; this is apt to be interfered with by condensation of water on the glass during the course of experiment; this drawback may, however, be nearly entirely obviated by smearing the inside of the glass with glycerine.

In the chest are two MARIOTTE'S flasks, C and D, each of a capacity of about four litres. The flasks are entirely similar in all respects, but for the sake of clearness in the diagram the tubes only have been represented in connexion with C, while the water-jacket which surrounds each flask is only indicated with D. This jacket, E, is merely a cylindrical tinned-iron bucket, somewhat wider than the flask. It is filled with water, and has, in connexion with it, a syphon by which it can be readily emptied, and a supply tube through which it can be filled. The syphon and supply tube have been omitted in the figure. Their ends pass outside the warm chamber, so that the water in the jackets can be changed without opening the box. As the flask empties of blood when in use, it tends to float up in the water of the vessel E. This is prevented by the collar *a*, which fits round the neck of the flask, and is attached by the bars *b*, *b*, to the upper edge of E.

In connexion with C are shown the tubes which pass through the air-tight cork of each MARIOTTE's flask. These are four in number. Two (*c*, *d*) are used when the flask is to be filled with blood; the other two (*e*, *f*) are employed when the flask is at work supplying the heart. When C is to be filled, the tubes *e* and *f* are closed by clamps or stopcocks put on the pieces of rubber tubing attached to their upper ends. The clamp *g* on the rubber tube attached to the upper end of *d* (which tubing, as shown in the figure, passes through an aperture, G, in the roof of the chamber) is opened, as is also the stopcock *h*, which is placed on the course of the tube leading from *c* to the funnel F. Meanwhile the corresponding stopcock *h'*, on the tube leading to the flask D, is closed. Defibrinated blood poured into F then enters the flask C through *c*, and the air which it displaces is driven out through *d*. C having been four-fifths filled, the stopcock *h* and the clamp *g* are closed, and the clamp *i* opened.

From the tube *f*, which dips deepest into the flask C, leads the rubber tube *k*; this passes through the end B of the warm chamber, and the next part of its course is shown in Plate 48, fig. 2, where *k* is seen to lead to the stopcock *l*, which is connected with one limb of the Y-piece *m*, another limb of which is attached to the corresponding tube *k'*, leading from the flask D. The remaining limb of the Y-piece leads to the rubber tube *n*, which is seen again in fig. 1, after entering the warm chamber. There *n* is seen to be continuous with the T-piece *o*, in the vertical limb of which is the thermometer *p*. Beyond the T-piece is the stopcock *q*, which ends in the rubber tubing *y*.

The flask C having been filled, we next go to the flask D, in connexion with which much of the details of the tubing have been omitted; but in all respects the flasks C and D and their connexions are similar. In the lettering of the figures whenever a connexion of C is indicated by a letter, the corresponding connexion of D is indicated by the same letter with a dash: *h* of C answers to *h'* of D; *d* of C to *d'* of D; *i* of C to *i'* of D, and so forth; so that a detailed description of the tubes connected with D is unnecessary.

To fill D the stopcock *h* is closed, and *h'* opened, as is also *g'*, while *i'* and *k'* are closed. Defibrinated blood poured into F then enters the flask D, and is added until that flask is about one-fourth filled. Then the stopcock *h'* is closed, the clamp *g'* screwed up, and the clamp *i'* opened. The further course of *k'* is seen in Plate 48, fig. 2, where it is shown as joining *k* at *m*; it therefore ends also in the stopcock and rubber tubing *q* and *y*.

So far we have got the flask C four-fifths full of defibrinated blood and the flask D one-fourth full. It remains to fill the tube *f* and its fellow, and the system of tubes leading from both of them to the stopcock *q*, which during an experiment is connected with the superior vena cava, and has to supply the heart steadily with defibrinated blood. The tube *f* and its fellow have to act as syphons, and therefore the lower ends of *f* and *f′* must be above the level of the exit of *q*. To secure this, both flasks, C and D, are suspended by cords *r*, *r′*, which support each flask and its water-jacket. These cords pass over pulleys borne on a framework, H, I, J, K, attached to the roof of the warm chamber, and each passes at its distal end round a fastener, *s*; by means of these cords the MARIOTTE's flasks can be raised and maintained at any desired level within the warm chamber. In the series of experiments here described both flasks were raised to the same height, although in fig. 1, C has been drawn lower than D for the sake of showing their connexions more clearly in the drawing.

To fill the syphon connected with C, the stopcock *h* and the clamp *g* are closed; the clamp *i* is left open, as is the stopcock *l* (Plate 48, fig. 2), while *l′* is kept shut. Then *q* (fig. 1) is opened, and suction applied to the end of *y*; blood then flows out of C through *f*, while air enters through *e*; and this blood is supplied to *y* under constant pressure.

The cock *q* is now closed, as also *h′* and the clamp *g′*. The clamp *i′* is left open, the stopcock *l* (Plate 48, fig. 2) closed, and *l′* opened. When *q* is now once more opened and suction applied to *y*, blood from D passes out by the tube *k′* and reaches *q* through the tube *n* (fig. 1). D now, like C, behaves as a MARIOTTE's flask, and supplies blood to *y* under a constant pressure. If both flasks be raised to the same height above the level of the superior vena cava, with which *y* (as will be described immediately) is connected, we can supply a heart with blood from either flask at will. When the stopcock *l* (Plate 48, fig. 2) is open and *l′* closed, the heart is fed from the flask C; when *l* is closed and *l′* opened, the blood is derived from D.

The flasks and the syphon tubes are filled as above described before the operation on the Dog is commenced, and the stopcocks so arranged (*l* open and *l′* closed) that on opening *q* blood will be drawn from C.

The water-jackets around each flask being filled, the gas burners under the trough which supports the warm chamber are lighted. From time to time *q* is opened, and blood from C let flow through it. When the temperature of this blood, as indicated by the thermometer *p*, is about 37° C., the gas is turned low and the operation on the Dog, described above, is proceeded with. While the flasks are warming *g* and *g′* are left open to allow some of the air in each flask to escape as it becomes expanded by the heat. Just before transferring the animal to the warm chest, *g* is screwed up, but *g′* left open; *h′* is also opened, and care is taken that *h* is shut. Under these circumstances C supplies blood to *y* when *q* is opened, while D (only one-fourth filled) is cut off from all connexion with *q* but is ready to receive any blood poured into it from the funnel F, or flowing to it through the tube L.

When the animal is transferred to the chamber the portable MARIOTTE's flask (Plate 48, fig. 3) is carried along with it by an assistant, and still supplies the heart with blood. A bit of brass tubing, *u* (fig. 1), inserted into the lower end of the tube, *t*, is now connected with the distal end of the piece of rubber tubing, *v* (Plate 48, figs. 1 and 3), attached to the distal end of the aortic cannula. The clamp *w* is then opened wide and the left ventricle pumps into and fills the tube *t*, from whose distal end the blood enters the funnel *x*; from this funnel it passes along L to the stopcock *h'* and thence to the flask D. The tube *t* has a bore at least as wide as that of the thoracic aorta of the animal, so that the heart pumps freely into it.

Next, the superior vena cava cannula *z* (Plate 48, fig. 3) is slipped out of the rubber tube connecting it with the portable MARIOTTE's flask U, and quickly inserted into *y* (fig. 1), care being taken that *y* is first filled with blood. The stopcock *q* being then opened, the heart is steadily supplied with blood from C. This blood, after traversing the lungs, is driven out of the left ventricle through *t*, and flows back to D, where it collects; accordingly as C empties D fills. When C is nearly exhausted the stopcock *h'* is closed, and also the clamp *g'*; *i'* is opened, as is also the stopcock *l'* (Plate 48, fig. 2). Simultaneously *h* and *g* are opened, and *i* and *l* closed. D now becomes the feeding and C the recipient flask. When D in turn is empty and C full the reverse steps to those above described make C the supplying and D the receiving flask; and so on as often as necessary in the course of an experiment. As all the clamps and stopcocks lie outside the warm chamber the connexion of the flasks with the heart can be changed when desired without opening the chamber. During an experiment the tube L and the part of *t* outside the warm chamber are kept wrapped in raw cotton, as also the funnel *x*; and the openings G and G' are loosely covered with damp cloths.

To return to the steps immediately following the placing of the animal in the warm chest: *y* having been connected with the superior vena cava, the bellows hitherto used are disconnected from the tracheal cannula, and over this is slipped the delivery tube of one of the convenient respiration engines, driven by water pressure, manufactured by the Cambridge Scientific Instrument Company; this engine henceforth maintains uniform artificial respiration: its delivery tube is not represented in the figure, but enters the warm chest through an aperture in its back. Next a clamp is placed on the left subclavian artery, close to its origin. The vessel is opened between this and the ligature previously placed on it, and the bulb of a thermometer inserted into the artery. The clamp being removed, the thermometer is pushed down until its bulb projects into the aortic arch, and is then firmly tied in that position.

Finally the cannula M is placed in the right carotid of the Dog and the cannula N in the left, and the clamps on those vessels removed. These cannulas are in connexion with the lead tubes O and P, which pass out through the end B of the warm chamber, and are connected with manometers. One manometer is a FICK's spring manometer, and is used for indicating the pulse-rate; the other is a mean pressure mercury manometer, after MAREY, having in its bend a stopcock which is nearly closed, so that each pulse-beat is hardly visible on the tracing, but the mean pressure at any time in the carotid is indicated.* The pens of both manometers write over one another on the paper of a LUDWIG's large kymograph. Below them, in the same vertical line, a chronograph pen inscribes seconds.

---

* In some of the earlier experiments only a mercury manometer was used. Owing to the doubts

As soon as the carotid cannulas are inserted the front of the warm chamber (which had been removed to admit of placing the animal inside and performing the above described manipulations) is replaced. The gas burners below the trough supporting the warm chamber are turned up, and a pause made before beginning observations until the air in the chamber, which has been much cooled while the front was away, is again heated up to about 38° C.; and also until at least twenty minutes have elapsed since the complete occlusion of all the systemic circulation except that through the coronary vessels. Before the lapse of this time all signs of any activity of the extra-cardiac nerve centres cease, and the physiologically isolated heart is ready for experiment under conditions in which venous pressure, arterial pressure, and the temperature of the blood flowing through it are under very complete control.

By raising or lowering the MARIOTTE's flasks, C and D, venous pressure (*i.e.*, the pressure under which blood enters the right auricle) can be varied within wide limits. In the experiments described in the present paper it was always kept at that exerted by the weight of a column of defibrinated Calf's blood 15 centims. in height, except when the contrary is expressly stated. Aortic pressure can be varied by sliding the support Q, which carries with it the exit of the aortic outflow tube, up or down the vertical rod R. Only the lower part of this rod is represented in the figure; its upper end reaches to the ceiling of the room. In most experiments the height of Q was arranged so that the mean pressure in the carotid was about 100 millims. of mercury. I had supposed before trial that I could in this way keep mean arterial pressure absolutely constant. But in spite of the small resistance offered by the wide aortic cannula and the wide system of tubes leading from it to the outflow point S, it turned out that the pressure as measured in the carotid (and therefore in the aortic arch) did not depend entirely and simply on the difference of level between the root of the aorta and the aperture of S. The left ventricle pumped out so much blood as to get up some elastic tension in the aortic arch and the arterial stumps still connected with it, and the pressure due to this was added to that dependent on the height of the column of blood against which the heart worked and on friction in the outflow tubes through which it was driven. So long as the heart works with sufficient force to pump blood up to and out of S the resistance due to the weight of the column of blood to be lifted remains the same; if the rate of flow be slower, the resistance, and therefore the increased pressure due to friction, will be diminished, but in such wide tubes probably only to a trivial extent. When, however, any cause, such as change in temperature, deterioration in quality of the blood supply, impediment in the pulmonary flow, or gradual death of the isolated heart, influences the amount of blood pumped out in the unit of time by

---

which have been cast upon the accuracy of this instrument when a very slow or a very quick pulse is to be recorded, the FICK manometer was subsequently added. It turned out, however, that this was unnecessary; the pulse-rate recorded by both manometers was exactly the same.

the left ventricle, then the elastic reaction due to distension of the stumps of the great arteries is altered. Hence, even while a heart is pumping blood freely out through the exit S, kept at a constant height, variation of arterial pressure, as measured in the carotid, may occur to the extent of 10 millims. of mercury pressure. Such variations will be noticed in some of the protocols of experiments given in this paper; but fortunately they in no way affect the question here considered, viz.: the influence of changes of temperature upon the rate of beat of the isolated heart. I have previously shown (2) that slow variations of arterial pressure between the limits of 30 and 150 millims. of mercury do not in the least influence the pulse-rate of the isolated Dog's heart, provided venous pressure and the composition and temperature of the blood be kept constant.

Venous pressure and, approximately, arterial pressure being kept uniform the temperature of the blood alone was altered in the experiments below described. The variation was effected in two ways. First by pouring a little heated (50° C.) or cooled (10° C.) blood into the funnel F from which it entered the flask not in use at that moment, and warmed or cooled the blood already in it. Then this flask was used to feed the heart and the other as the recipient, by opening and closing the proper clamps and stopcocks. This method was rarely used, as it sometimes produced secondary effects, due to the comparatively sudden changes of temperature in the blood supplied to the heart. A more gradual and uniform alteration in the temperature of the blood was secured by changing the water in the jackets around the MARIOTTE's flasks. Some hot water and some water cooled by ice to 5° or 10° C. were always kept at hand during an experiment. If a series of heating observations was to be made, some of the water already in the jackets was syphoned off, and replaced with warm, care being taken that the temperature never rose above 60° C., so as to avoid all risk of coagulating any of the proteids of the defibrinated blood: more hot water was added from time to time if necessary. To initiate a series of observations as to the effect of cooling, the iced water was of course employed. The best results were obtained when the temperature of the water in the jackets did not differ by more than 20° from the temperature of the blood in the flask. When either MARIOTTE's flask was in use the rapid bubbling through its contents of the air entering by the tubes *e* and *e′* ensured their thorough mixture.

Having waited, then, for the death of extrinsic nerve centres, and until the thermometer *p* had during some minutes indicated a tolerably even temperature, the water around the MARIOTTE's flasks was cooled or heated, and a series of observations commenced. The initial temperature usually lay between 37° and 38°, but, as will be seen in the experiment protocols which follow, was sometimes higher or lower. Tracings of arterial pressure and pulse-rate were taken at intervals varying from one to five minutes. When the tracing was completed an assistant immediately opened a small door in the front of the warm chamber, and read off the temperature of the blood flowing through the heart.

As regards this temperature, the question arose which thermometer to use; that, *p*, in the inflow tube, or that pushed down the left subclavian to the aortic arch. The former gave the temperature of the blood flowing through the cavity of the right heart; the latter the temperature of the blood in the left auricle and ventricle and aorta, and accordingly in the coronary arteries supplying the cardiac capillaries. *À priori*, there seemed little doubt that it would be the temperature of this latter blood, brought as it was into close relation with every muscle fibre and ganglion cell in the heart, which would exert an influence on the cardiac rhythm, if any did. Experiment soon confirmed this. Both thermometers were read in several experiments, and it was always found that the pulse-rate changes followed much more closely the variations of temperature indicated by the instrument in the subclavian. In most cases, accordingly, only the reading of this thermometer was undertaken, as it was very desirable to reduce to a minimum the time during which the door of the warm chamber was open.

The temperature observed was written on the kymograph paper over the tracing, along with the time at which the latter had been taken. After a pause, another tracing was taken, time and temperature noted as before, and so on throughout the experiment, which was usually continued until the heart began to show symptoms of weakened or abnormal action.

The roll of tracings was subsequently gone over carefully, and on the graphic record of each observation periods of twenty seconds marked out; the pulses during that time were counted, and the mean arterial pressure measured. The results were then put in tabular form, the actual pulses counted being multiplied by three, so as to give the rate per minute instead of the number of beats in twenty seconds. In the "detailed results" given below, six such tables are printed; as curves present very quickly and accurately to the apprehension the general outcome of long columns of figures, charts have also been constructed (Plate 49) giving the curves of temperature variation and pulse-rate change during two of these experiments.

Detailed results of experiments.

Before proceeding to the following tables, which give the actual figures as to pulse-rate and temperature for several experiments, a few words of explanation are desirable with reference to some three or four points.

First, it will be noted that for normal temperatures (38-39° C. in the left ventricle of the Dog, according to CLAUDE BERNARD) (10) the pulse is very fast. This is undoubtedly due to the section of both pneumogastrics, cutting off the heart from control by the extrinsic cardio-inhibitory centre, which is normally very active in the heart of the Dog. Upon atropin paralysis of the peripheral pneumogastric connexions with the heart V. BEZOLD and BLŒBAUM (5) found in this animal the pulse-rate sometimes increased 80 per cent. An increase of 80 per cent. above the average will more than account for the quickest pulse observed by me at normal temperatures.

Second, it will be seen that, quite independent of any changes of temperature, the heart beats slower towards the end of an experiment than it did at the beginning, although its action may still be regular and each pulsation powerful. This is undoubtedly due to altered nutrition resulting from the use of Calf's blood, as it was not observed, or at least not until much later in my earlier experiments (2), when Dog's blood was employed. In consequence of this gradual and progressive slowing of the pulse it might be objected in a cooling experiment that any observed diminution of the rate of heart-beat was dependent on other conditions than cooling of the organ. To meet this objection, in most instances after a series of cooling observations a series of heating has been made on the same heart, and these show that in every case the heart beats much quicker when again warmed. This makes it clear that the slow pulse previously observed was not due merely to progressive malnutrition of the isolated heart, but was mainly dependent on the lower temperature to which the organ was exposed. Taking for example Experiment I., we find that at 1^h 34^m P.M. the heart beat 246 times a minute at the temperature of 37°·8 C. Forty-three minutes later (at 2^h 17^m P.M.) it beat only 217 times per minute at the temperature 38°·1 C; but meantime the pulse-rate, at 1^h 57^m M.P., had been down to 73 per minute, the temperature being 27°·8 C. This slow pulse being followed twenty minutes later by one nearly three times as fast cannot of course have been conditioned by any progressive diminution of functional capacity dependent on the prolonged use of Calf's blood; this becomes still more obvious when, later on in the same experiment, we find a second cooling accompanied by a slower pulse, and a second heating by a quicker.

Third, it may be noted that in no case does any one of the experiments given last longer than two hours, and that, with one exception (Experiment VI.), it is stated that the observations had ceased because of some obvious abnormality in the heart's action. In my earlier experiments with isolated hearts a practically normal beat often lasted for four hours or longer. They were however carried out on a different plan, which allowed of the use of defibrinated Dog's blood to nourish the heart. Instead of permitting the left ventricle to pump blood out through a wide aortic cannula, the only exit left was through a narrow cannula in one carotid, and, in correspondence with this fact, the tube supplying the superior cava was also narrow. In the present series of experiments the widest possible cannulæ was placed in the aorta and vena cava, and all the tubing attached to these, and the stopcocks upon it, had a bore as wide as that of the cannulæ. Under such circumstances the heart pumps round three or four litres of blood in a very few minutes, and with a smaller amount the stopcocks and clamps used to make the flasks C and D alternately feeding and recipient, would have to be changed at such short intervals as to make it impossible to carry on any uniform series of consecutive observations. With the original method 1000 to 1500 cubic centims. of whipped blood was enough for convenient use, and this quantity it was possible to obtain from Dogs. When four litres or more of blood are wanted it becomes practically impossible to use Dog's blood, and so some other had to be selected. After several trials Calf's blood was chosen. This blood, however, nourishes the heart less satisfactorily, and hence the earlier indications of commencing death.

With respect to the choice of blood I add a few words which may be of aid to any one desirous to repeat my experiments. It is important to have it from quite young Calves; that is to say, from animals which are still suckling: a point of itself of some interest when considered in connexion with the well known fact that the chemical composition of the urine of the nurslings of Herbivora shows that their nutritional processes agree in the main with those of adult Carnivora, and differ essentially from those of the adults of their own species. In spite of all care I used to be frequently disappointed by the death of the isolated heart before any satisfactory number of observations could be carried out upon it, even in cases when I could think of no cause for the failure. Light broke upon me when the laboratory attendant, whose duty it was to bring the blood from the slaughter-house, remarked one day that it seemed to him that we nearly always got on better when he did not get the blood from "wharf calves." On questioning, I found that "wharf calves" was the term employed by Baltimore butchers to indicate animals which, though still young enough to yield veal, were of such age that they had long ceased to live on milk. Since the blood of such Calves has been rejected the percentage of failures has considerably decreased. It is hardly necessary to add that care must be taken that no extraneous matter enters the blood during its collection. Baltimore butchers stun the Calves and then cut their throats, and while the blood flows out vomiting frequently occurs and sends the contents of the stomach into the collecting pail. The blood from each animal has therefore to be collected separately, so that the quantity already obtained may not be rendered unfit for use by admixture with matters from the stomach of another animal.

Even with the best obtainable Calf's blood, however, the results are not as satisfactory as with Dog's blood. Not only does the heart die sooner, but other changes occur which shorten the time during which an experiment can be carried on. The most marked of these is lung œdema, which nearly always takes place in the course of an hour and a half, to such an extent as to seriously impede the pulmonary circulation and the æration of the blood in the lungs. In consequence, the supply of blood to the left heart is hindered, and the right heart becomes gorged, and its auricle finally paralyzed; and this, of course, puts an end to an experiment. Another trouble which is apt to occur when Calf's blood is used is considerable pericardial exudation, often to such an extent as to seriously interfere with the beat of the heart. This difficulty may, however, be readily avoided by cutting a small hole in the pericardium as soon as the heart is placed in the warm chamber. A third difficulty met with when Calf's blood is employed is more serious. Many observers have noted on the isolated Frog's heart, supplied with various nutrient liquids, a gradual increase in the bulk of the organ in the course of a prolonged experiment; this increase being due, apparently, to an alteration in the elastic modulus of the cardiac muscle. The same phenomenon is observed when a Dog's heart is fed with Calf's blood. Gradually the systolic size of the organ increases, until at last, even at the height of its systole, the heart very nearly fills the pericardiac sac. During the subsequent diastole there is, therefore, but little opportunity for the organ to expand and receive blood. When this state of things takes place, one sees on the tracings that a good arterial pressure is still maintained, and that the heart rhythm is regular, but the height of each pulse curve is much diminished; and on looking at the exit (Plate 48, fig. 1, S) of the aortic outflow tube, it is seen that the quantity of blood expelled at each systole is markedly decreased. If the heart be then examined it will be found so distended as to tightly fill the pericardium, and if the latter be carefully cut away the pulse-rate remains unaltered; but the heart now does again nearly, or quite, its original work: the pulse-curves on the tracing regain their previous extent, and the gush from the aortic outflow tube at each systole becomes as great as it was before the occurrence of the distension of the heart. The impediment to the heart's action, due to this expansion, may be avoided either by cutting away the pericardium before beginning a set of observations or by removing it later when it begins to interfere with the heart's action. Both methods have been used in the course of the experiments whose results are given in the present paper. In selecting special examples for publication it seemed best, however, to include, mainly, cases in which the normal state of things had been interfered with as little as possible; and in none of the tables which follow was the pericardium cut away before the commencement of the observations, and in only two cases (Experiments II. and IV.) during their progress. It seemed desirable to include these for the purpose of showing that, although the heart's effective work is much diminished when it has become so distended as to fill the pericardium, yet its rate and force of beat are unaltered.

The ill results of pulmonary œdema above described may be obviated to a great extent by pricking numerous holes in the lungs with a fine needle. This allows the liquid collected in the air cells and small bronchial tubes to escape, and relieves the pressure on the pulmonary capillaries, while it also allows air to reach the air cells. This operation in no way affects the general result so far as pulse-rate is concerned, the chief objection to it being the loss of blood due to trickling from the wounds. To avoid objections, only one case (Experiment IV.) in which the lungs were so pricked is included in the experiments detailed in the present communication.

Before leaving this question of the troubles attending the use of Calf's blood, I may state that some considerable experience has led me to the conclusion that the drawbacks more than balance the advantages, at least in so far as most experiments are concerned. If I had to repeat the investigation here described, I should certainly tie the aorta just beyond its arch, and connect the outflow tube *t* with the left carotid instead of with the aorta; pulse-rate and mean pressure could then be recorded by manometers placed in the right subclavian and carotid arteries, and in correlation with the narrowed outflow orifice, the feeding tube, *n*, of the heart could be narrowed. Under such circumstances much less blood would be pumped around in a given time, and it would be possible to obtain the quantity requisite for carrying on an experiment from Dogs instead of from Calves. Pulmonary œdema and loss of cardiac elasticity would then occur much later. Of course in other cases, as when, for example, the greatest amount of blood which could be forced out from the left ventricle in a systole was to be sought, or the work done by the left ventricle under varying conditions, it would be necessary to use the wide tubes and stopcocks which I have above described, and these would almost necessarily lead to the use of other than Dogs' blood for the nourishment of the isolated heart.

Fourth, as a final remark before proceeding to give experiment protocols, I call attention to the fact that in the following tables it will be seen that now and then a slight rise of temperature occurs in the course of a cooling experiment, or a slight fall in the course of a heating. Such breaks were nearly always due to the necessity of changing the feeding MARIOTTE's flasks from time to time. While C is emptying and D filling, it is not possible to ensure that when D is in turn connected with the heart, the blood in it shall always be exactly of such temperature as to fit into the series of cooling or heating observations which had been carried on with C. An endeavour was always made to make the observations with the alternate flasks regularly consecutive as regards changes of temperature, and it will be seen that, in most cases, this was attained. When it was not, the resulting temporary rises or falls of temperature serve only to verify the general result; a slight and transitory heating in the course of a general cooling experiment quickens the pulse, and *vice versâ*.

I now give, in tabular form, the results of six experiments.

Experiment I.

April 24, 1882.—The Dog used weighed 5790 grms. and was chloroformed during the operation of isolating the heart. Venous pressure throughout equal to that exerted by a column of defibrinated Calf's blood 15 centims. in height. Arterial pressure, measured in the right carotid, varied between 97 and 104 millims. of mercury. All the systemic vessels but those of the coronary system of the heart were occluded at 12^{h} 50^{m} P.M.

Number of observation.	Time, P.M.		Temperature, centigrade, indicated by thermometer passed through left subclavian to aortic arch.	Pulse-rate per minute.	Remarks.
	h.	m.			
1	1	33	37·5	240	
2	1	34	37·8	246	
3	1	38	35·5	204	
4	1	40	34 8	191	
5	1	42	33·8	178	
6	1	44	32·0	153	
7	1	46	31·5	148	
8	1	48	30·5	129	
9	1	50	29·9	119	
10	1	52	29·0	105	
11	1	54	28·0	82	
12	1	57	27·8	73	
13	1	58	28·3	79·5	
14	2	01	29·0	83	
15	2	04	29·6	88	
16	2	06	31·1	129	
17	2	07	33·0	155	
18	2	08	33·9	168	
19	2	10	35·5	190	
20	2	11	37·0	207	
21	2	13	37·9	223	
22	2	14	36·8	203	
23	2	15	37·3	209	
24	2	17	38·1	217	
25	2	19	39·5	233	
26	2	20	40·5	240	
27	2	22	39·8	225	
28	2	26	39·5	219	
29	2	28	38·0	198	
30	2	30	36·8	181	
31	2	31	36·0	179	
32	2	34	34·5	159	
33	2	36	34·5	160	
34	2	38	32·8	131	
35	2	39	31·8	114	
36	2	41	30·8	87	
37	2	43	30·3	84	
38	2	45	30·5	80	Irregular.
39	2	46	30·8	81	Regular.
40	2	47	31·3	84	Slightly irregular.
41	2	49	31·5	87	Regular.
42	2	51	32·1	118·5	
43	2	53	32·5	126	
44	2	55	33·1	135	
45	2	59	36·5	184	
46	3	00	36·3	160	
47	3	02	35·8	167	The pulse now became very irregular, and its rate fell rapidly in spite of a supply of warmer blood to the heart.

The results of Experiment I. are represented graphically on Plate 49. Each division along the abscissa corresponds to two minutes of time. The level of the abscissa line answers to a temperature of 25° C. and to a pulse-rate of 60 per minute. The continuous curve represents the pulse variations during the experiment. Each division on the height of ordinates drawn from any point of the pulse curve to the abscissa answers to ten pulse beats more than 60 per minute. The dotted curve represents the temperature variations. Each division of height in ordinates drawn from it to the abscissa represents one degree centigrade above 25°. It will be observed that the curves of temperature and pulse-rate fall and rise together throughout the experiment.

Experiment II.

April 27, 1882.—The Dog weighed 5550 grms. Chloroform and ether administered during the operation of isolating the heart. Venous pressure that exerted by a column of defibrinated Calf's blood 15 centims. in height. All the systemic vessels but those supplying the heart itself were ligated at 3^{h} 10^{m} P.M. The animal was transferred to the warm chamber at 3^{h} 15^{m} P.M., and then decapitated and a stout wire run down the spinal canal as far as the lumbar region before any observations as to pulse-rate were made.

Number of observation.	Time, P.M.		Arterial pressure in left carotid, in millims. of Hg.	Temperature in aortic arch.	Pulse-rate per minute.	Remarks.
	h.	m.				
1	3	30	100	38·0	237	
2	3	33	102	37·9	234	Since last observation one carotid cannula had slipped out and been replaced.
3	3	40	99	38·5	241·5	
4	3	42	98	38·5	244	
5	3	44	98	41·5	273	
6	3	46	101	40·5	258	
7	3	47	99	40·9	261	
8	3	48	100	42·0	267	
9	3	52	100	42·0	265·5	
10	3	53	99	42·5	265·5	
11	3	54	100	42·5	250	
12	3	55	97	39·5	222	Flask changed since last observation; hence the rapid alteration of temperature.
13	3	57	97	37·0	198	
14	3	58	97	36·0	189	
15	3	59	97	35·5	175·5	
16	4	00	98	34·7	169	
17	4	01	97	34·0	162	
18	4	02	98	34·0	165	
19	4	04	98	33·9	153	
20	4	05	99	32·9	144	
21	4	06	100	32·5	140	
22	4	09	98	31·7	124·5	
23	4	11	100	30·1	105	Pericardium cut away since last observation.
24	4	12	100	30·0	105	
25	4	15	101	29·9	97	
26	4	17	101	29·5	88	
27	4	19	101	29·0	84	
28	4	21	103	28·5	76	
29	4	23	104	27·5	75	
30	4	26	108	27·3	66	
31	4	27	112	28·0	66	
32	4	30	108	28·1	69	
33	4	32	108	29·5	111	
34	4	33	108	31·5	129	
35	4	34	107	32·5	162	
36	4	35	109	34·0	183	
37	4	36	105	35(?)	150	
38	4	37	107	34·1	144	
39	4	39	105	33·5	135	
40	4	41	106	33·5	133·5	
41	4	43	105	34·0	135	Pulse irregular.
42	4	44	102	34·7	117	Pulse regular.
43	4	46	..	..	..	Heart's beat now became very irregular and experiment was discontinued.

Experiment II. presents two points of special interest: in the first place the brain was removed and the cervical and dorsal spinal cord destroyed before the observations commenced, so that an additional security was obtained that no cerebro-spinal centres were influencing the pulse rate. In the second place it is one of the cases in which the heart became considerably distended during the course of the experiment, so that the pericardium had to be cut away. As will be seen, this did not at all affect the general result.

Experiment III.

May 3, 1882.—Dog weighed 6000 grms. Narcotised by subcutaneous injection of acetate of morphia before the operation of isolating the heart was commenced. Venous pressure at first that due to a column of whipped blood 10 centims. high, and afterwards to a column 15 centims. in height. Heart isolated at 12^{h} 55^{m} P.M.

Number of observation.	Time, P.M.		Carotid pressure in millims. of Hg.	Temperature. C.° in aortic thermometer.	Pulse-rate per minute.	Remarks.
	h.	m.				
1	1	20	110	34·5	151·5	Venous pressure 10 centims.
2	1	23	110	34·9	162	
3	1	25	110	36·1	185	
4	1	27	110	36·1	186	
5	1	29	110	37·9	211	
6	1	30	110	39·3	225	
7	1	31	110	40·0	232·5	
8	1	33	111	40·5	235	
9	1	35	110	40·3	222	
10	1	38	110	38·5	202·5	
11	1	41	109	37·0	184·5	Venous pressure raised to 15 centims. between observations 10 and 11.
12	1	43	110	36·9	195	
13	1	45	110	35·5	168	
14	1	46	112	33·9	152	
15	1	49	110	33·5	156	
16	1	51	110	32·7	142	
17	1	53	110	32·1	129	
18	1	55	111	30·0	102	
19	1	57	111	29·1	94·5	
20	1	58	110	28·9	87	
21	1	59	96	28·0	67·5	Heart weakens and ceases to pump round before next observation.
22	2	06	42	31·5	63	
23	2	08	..	..	..	
24	2	10	..	..	..	Heart beat irregular and experiment discontinued.

Experiment IV.

May 10, 1882.—Dog weighed 10,300 grms. Narcotised by subcutaneous injection of acetate of morphia before commencing the operation of isolating the heart. Venous pressure that due to a column of defibrinated Calf's blood 15 centims. in height. Heart isolated at $12^{h}\ 25^{m}$ P.M.

Number of observation.	Time, P.M.		Carotid pressure in millims. of Hg.	Temperature in aortic arch.	Pulse-rate per minute.	Remarks.
	h.	m.				
1	12	45	118	34·1(?)	158	It seems almost certain that the reading of the thermometer in observation 1 was a degree out, and should be 35·1°.
2	12	47	117	34·5	151	
3	12	49	116	35·1	157	
4	12	51	116	35·5	156	
5	12	53	116	37·1	183	
6	12	54	116	39·0	195	
7	12	55	116	38·0	180	
8	12	56	116	38·3	181·5	
9	12	58	116	38·5	184·5	
10	12	59	116	38·5	183·0	
11	1	00	116	38·0	172·5	
12	1	02	112	37·5	166·5	
13	1	03	113	36·5	157·5	
14	1	05	112	35·0	137·0	
15	1	06	114	34·0	127·5	
16	1	08	114	33·5	126·0	
17	1	09	112	33·5	126·0	
18	1	11	111	32·7	114	
19	1	13	110	31·9	108	
20	1	14	111	31·5	102	
21	1	15	113	31·0	99	
22	1	17	113	30·5	92	
23	1	20	112	31·5	110	
24	1	22	112	32·5	119	
25	1	24	110	33·9	133·5	
26	1	27	110	34·0	129	Lungs pricked since last observation.
27	1	30	113	34·5	139·5	
28	1	32	114	35·0	140	
29	1	34	114	35·5	148	
30	1	37	(?)	36·5	179	Pericardium cut away since last observation.
31	1	38	101	38·0	192	
32	1	39	105	39·0	198	
33	1	40	107	39·6	199	
34	1	42	108	39·0	189	
						After this the heart suddenly ceased to pump round, and its right auricle was seen to be paralysed. The lungs were extremely œdematous.

The chart on Plate 49 represents graphically the results of the preceding experiment.

Experiment V.

May 22, 1882.—Dog weighed 5605 grms. Chloroform administered while the heart was being isolated. Venous pressure at first that due to a column of defibrinated Calf's blood 10 centims. in height, then doubled. Temperatures taken both in inflow tube (by thermometer *p*, Plate 48, fig. 1) and in the aortic arch by a cannula thrust down the left subclavian artery. Heart isolated at 1^h 30^m P.M. The mean temperature given in the sixth column is obtained by adding together the inflow and outflow temperatures and dividing by 2. It does not really represent the mean temperature of the heart, as while the inflow temperature is that of the blood in right auricle and ventricle, and the outflow (aortic) temperature that in left auricle and ventricle, the latter is also the temperature of the blood circulating in the walls of the heart itself.

Number of observation.	Time, P.M.	Carotid pressure in millims. of Hg.	Inflow temperature.	Outflow (aortic) temperature.	Mean temperature.	Pulse-rate per minute.	Remarks.
	h. m.						
1	1 55	94	36·3	36·5	36·4	227	Venous pressure 10 centims.
2	2 00	94	37·3	37·3	37·3	234	
3	2 05	94	37·3	37·5	37·4	238	
4	2 10	94	37·5	36·7	37·1	225	
5	2 12	93	38·5	37·5	38·0	231	
6	2 14	96	39·5	39·0	39·2	249	Venous pressure raised to 20 centims.
7	2 16	96	38·0	38·5	38·2	244·5	
8	2 18	96	38·5	38·3	38·4	238·5	
9	2 20	97	39·0	38·7	38·8	241	
10	2 23	94	39·1	39·0	39·0	244	
11	2 25	94	40·3	39·7	40·0	249	
12	2 27	95	40·7	40·1	40·4	252	
13	2 30	97	40·0	39·9	39·9	252	
14	2 33	92	40·0	39·7	39·8	243	
15	2 35	92	40·0	39·5	39·7	233	
16	2 38	52	(?)	(?)	..	102	Pulse very suddenly slowed and became somewhat irregular and experiment discontinued.

Experiment VI.

May 22, 1882.—Dog weighed 1140 grms. Chloroformed while the heart was being isolated. Venous pressure throughout that due to a column of defibrinated Calf's blood 20 centims. in height. Heart isolated at 3ʰ 40ᵐ P.M.

Number of observation.	Time, P.M.		Carotid pressure in millims. of Hg.	Temperature of aortic blood.	Pulse-rate per minute.	Remarks.
	h.	m.				
1	4	05	101	37·5	173	
2	4	07	99	36·9	170	
3	4	09	98	36·7	163·5	
4	4	14	98	36·7	156	
5	4	17	97	36·0	145·5	
6	4	20	97	35·1	132	
7	4	22	98	34·6	126	
8	4	23	98	34·1	117	
9	4	25	99	33·5	114	
10	4	28	97	33·0	108	
11	4	30	97	32·3	105	
12	4	32	96	32·5	91	
13	4	33	98	31·5	85	
14	4	34	98	31·1	85·5	
15	4	36	96	30·5	73·5	
16	4	37	96	30·1	76	
17	4	39	98	29·9	68	
18	4	41	95	29·5	69	
19	4	43	98	29·3	61	
20	4	45	98	28·9	63	
21	4	47	96	28·7	55·5	
22	4	51	98	28·7	61	
23	4	55	94	28·5	54	
24	4	57	97	28·5	54	
25	5	00	97	28·3	48	
26	5	03	96	28·1	52	
27	5	05	96	27·7	43	
28	5	08	94	27·5	28	Pulse irregular but each beat powerful.
29	5	10	90	27·6	24	
30	5	12	90	27·6	24	
31	5	14	92	27·6	21	
32	5	16	82	27·3	19·5	Heart ceases to pump blood to top of aortic outflow tube.
33	5	18	67	27·3	21	
34	5	21	58	27·1	21	
35	5	23	52	27·3	18	
36	5	25	49	27·3	18	
37	5	27	51	27·5	21	
38	5	30	45	28·0	19·5	
39	5	35	70	28·0	40·5	Pumps round again.
40	5	37	92	28·3	48	
41	5	40	93	28·5	58	
42	5	42	94	28·7	66	
43	5	43	96	29·1	73	
44	5	45	95	29·9	76	
45	5	49	93	30·5	82·5	
46	5	51	93	31·5	99	
						Experiment now discontinued. Heart still beating regularly and forcibly.

The above experiment is remarkable for the very slow pulse observed throughout. Even at 37°·5 the pulse was only 173 per minute, whereas in most isolated hearts it is over 200 at that temperature. When the temperature was brought down to near 27° the extraordinary slow pulse of 18 per minute resulted; a pulse so slow that although each beat was powerful the left ventricle pumped out in each minute less blood than was drained off from the aorta by the coronary arteries, so that the level of the blood in the aortic exit tube fell lower and lower until the carotid pressure finally came down to 41 millims. of mercury. On again heating the blood supplied to the heart the organ regained completely its functional activity. Before the cooling (observation 13) the pulse rate at the temperature 31°·5 was 85 per minute, and pressure in the carotid was 98 millims. of Hg. After the cooling, on again heating, we find at the same temperature (observation 46) a pulse of 99 per minute and a carotid pressure of 93 millims. of mercury. It is unfortunate that the experiment was not continued, but the exceptionally slow pulse obtained was not recognised until the tracings were counted out the next day, and as it was the second experiment of the same date I was fatigued and stopped so soon as I had satisfied myself that reheating the blood had quickened the pulse, instead of going on as usual until the heart began to show signs of commencing death.

Conclusions.

As regards the question which the preceding experiments were primarily designed to answer, their results are decisive. They make it clear that the Mammalian heart when quite cut off from all extraneous nervous control, and when supplied with blood which has not been altered in composition by products of abnormal tissue change, due to abnormal heating or cooling of other organs of the body, does beat quicker when warmer blood is supplied to it, and slower when it gets cooler blood. In this respect the heart of the Dog behaves quite like that of the Frog. In spite of the greater division of physiological duties in the body of the Mammal, and the greater subjection of the Mammalian heart to control from special extrinsic nerve centres, the Dog's heart in its own neuro-muscular apparatus is so constituted as to have its rate of periodic activity directly controlled by its temperature. To account for the quick pulse of fever we need therefore assume no paralysis of extrinsic cardio-inhibitory nerve centres and no excitation of cardio-accelerator. The warmed Mammalian heart beats quicker because of its own physiological properties.

In addition to the above main question, several subsidiary points have some light thrown upon them.

(1.) The rate of beat of the Mammalian heart does not directly depend upon the temperature of the blood reaching the right auricle, except in so far as this influences the temperature of the blood pumped out by the left ventricle and supplied to the coronary arteries. It is not the temperature of the blood in its cavities which influences the rate of beat of the Dog's heart, but the temperature of the blood sent to its capillaries. In other words, temperature changes do not influence the pulse-rate by stimulating afferent nerves in the endocardium which then act upon cardio-motor ganglia, but they act directly upon the muscle fibres or nerve cells of the organ.

(2.) A second subsidiary fact illustrated by the preceding experiments is that the heart of the Dog can be nourished for some time and kept in a good state of functional activity when fed only with Calf's blood: but this blood is far less satisfactory than Dog's blood, its use soon leading to pulmonary œdema and alteration of the elastic modulus of the cardiac muscular tissue.

(3.) As a third point of interest it may be noted that no clotting takes place in defibrinated blood circulated for some hours through the living heart and lungs. Such blood contains an abundance of fibrino-plastin (paraglobulin) and fibrin ferment, together with the quantity of salines necessary for the formation of fibrin if fibrinogen were present. Fibrinogen, therefore, is produced in other organs of the body than heart and lungs. By further experiments in which the isolated heart shall be connected with various other isolated organs and pump blood through them I hope to discover in what organs fibrinogen is produced.

It would have added much to the interest of the research described in the preceding pages if determinations had been made as to the highest and lowest temperatures at which the Dog's heart would beat, and I had hoped when commencing the investigation to have discovered those temperatures. It turned out, however, that with the method of work described in the preceding pages this was not possible. When the heart is considerably cooled, for example, it pumps around so little blood that the amount sent out at each systole of the left ventricle is less than that carried off by the coronary arteries. Under these circumstances the coronary system is mainly supplied with warm blood derived from the column of liquid accumulated in the aortic outflow tube (Plate 48, fig. 1, *t*.) As a consequence, the blood in the right heart comes to be of a very different temperature from that circulating in the cardiac capillaries, and the result is irregular and inco-ordinate action of the right and left sides of the heart, and a total cessation of all circulation. Quite similar results follow warming of the blood supplied to the right auricle to near the death temperature. Consequently I have not been able to discover the temperature limits of the vitality of the Dog's heart. Some preliminary experiments, carried on in a different manner, lead me to hope that the question as to the highest and lowest temperature at which a Dog's heart will beat can be solved; but my work in that connexion is not yet ready for publication.

References.

1. H. **Newell Martin**. "A New Method of Studying the Mammalian Heart." 'Studies from the Biological Laboratory, Johns Hopkins University,' vol. ii., p. 119, June, 1881.

2. ——————— "Observations upon the Direct Influence of Variations of Arterial Pressure upon the Rate of Beat of the Mammalian Heart." 'Studies from the Biological Laboratory,' vol. ii., p. 213, March, 1882.

3. ——————— "The Influence of Variations of Arterial Pressure, of Venous Pressure, and of Temperature upon the Pulse Rate of the Isolated Mammalian Heart." 'Transactions of the Medical and Chirurgical Faculty of Maryland,' 1882.

4. **Weismann**. "Ueber die Muskulatur des Herzens beim Menschen und in der Thierreihe." '**Reichert** und **Du Bois**' Archiv,' 1861, p. 41.

5. V. **Bezold** und **Blœbaum**. "Ueber die Einwirkung der Atropins auf die Herzbewegung bei Carnivora." 'Neue Würzburger Zeitung,' 1866, Nr. 129.

6. T. **Lauder Brunton**. "Influence of Temperature on the Pulsations of the Mammalian Heart and on the Action of the Vagus." 'Bartholomew's Hospital Reports,' vol. vii.

7. **Schenk**, J. L. "Zur Physiologie des Embryonalen Herzens." 'Sitzber. d. k. Akad. zu Wein,' Bd. 56, 2, p. 111.

8. **Wernicke**, R. "Zur Physiologie des Embryonalen Herzens." '**Preyer**'s Sammlungen,' 1876.

9. **Cleland**. "Note on the Effect of Heat on the Heart's Action in the Chick." 'Journ. of Anat. and Phys.,' vol. xi., p. 754.

10. **Claude Bernard**. 'Liquides de l'Organism,' tome i., chap. 5.

INDEX TO PART II.

OF THE

PHILOSOPHICAL TRANSACTIONS

FOR THE YEAR 1883.

B.

Bdellostoma, 394 (see Parker).

C.

Calamites, 465.

Carpenter (W. B.). Researches on the Foraminifera—Supplemental Memoir. On an Abyssal type of the Genus Orbitolites;—a Study in the Theory of Descent, 551.—Orbitolites tenuissima, 553; geographical, bathymetrical, and geological distribution, 558; relation to other Orbitoline types, 559; evolutionary history of the Orbitoline type, 567; theory of descent, 569; explanation of plates, 571.

Coal-Measures, fossil plants of, 459 (see Williamson).

Compass, change in the deviations of, on a change of magnetic latitude, 615.

Creak (E. W.). On the Changes which take place in the Deviations of the Standard Compass in the Iron Armour-plated, Iron, and Composite-built Ships of the Royal Navy, on a considerable change of Magnetic Latitude, 615.—General conclusions, 625.

Croonian Lecture (see Martin).

D.

Dadoxylon, 469.

De La Rue (W.) and Müller (H. W.). Experimental Researches on the Electric Discharge with the Chloride of Silver Battery.—Part IV. Tube potential, 477 (for index see p. 516).

Descent, theory of, 569.

E.

Electric discharge in rarefied gases, 477 (see De La Rue).

Electrical motions in a spherical conductor, 519.

F.

Foraminifera, 551 (see Carpenter).

Fossil plants of the Coal-Measures, 459 (see Williamson).

G.

Glucinum, atomic weight of, 601.

H.

Hag-fish, 376 (see Parker).

Halonia, 466 (see Williamson).

Heart, influence of temperature on rate of, 663 (see Martin).

Humpidge (T. S.). On the Atomic Weight of Glucinum (Beryllium) 601.

L.

Lamb (H.). On Electrical Motions in a Spherical Conductor, 519.

Lamprey, 412 (see Parker).

Lepidodendroid plants, 465 (see Williamson).

M.

Marsipobranch fishes, skeleton of the, 373 (see Parker).

Martin (H. N.) The Croonian Lecture.—The Direct Influence of Gradual Variations of Temperature upon the Rate of Beat of the Dog's Heart, 663—The method, 666; detailed results of experiments, 674; conclusions, 686; references, 688.

Meliolia, 583 (see Ward).

Molecular forces, experiments bearing on the distance to which they may be sensible, 645 (see Reinold).

Müller (H. W.) and De La Rue (W.) (see De La Rue).

Myxinoid fishes, 373 (see Parker).

O.

Orbitolites, 551 (see CARPENTER).

OWEN (R.). On the Affinities of Thylacoleo, 575

——— Pelvic characters of Thylacoleo Carnifex, 639.

P.

Palladium, Volatile alloy of, with hydrogen, 482 (see DE LA RUE).

PARKER (W. K.) On the Skeleton of the Marsipobranch Fishes.—Part I. The Myxinoids (Myxine and Bdellostoma), 373.—Hag Fish (Myxine glutinosa), 376; Bdellostoma, 394; summary and conclusion of Part I., 403; description of the plates, 407. Part II. Petromyzon, 411; embryo of Petromyzon, 439; summary and conclusion, 450; description of the plates, 454.

Psaronius, 464 (see WILLIAMSON).

R.

REINOLD (A. W.) and RÜCKER (A. W.). The Limiting Thickness of Liquid Films, 645; electrical experiments, 646; optical experiments, 652; summary of results, 660.

RÜCKER (A. W.) and REINOLD (A. W.) (see REINOLD).

S.

Sporocarpon, 469 (see WILLIAMSON).

T.

Thylacoleo, 575, 639 (see OWEN).

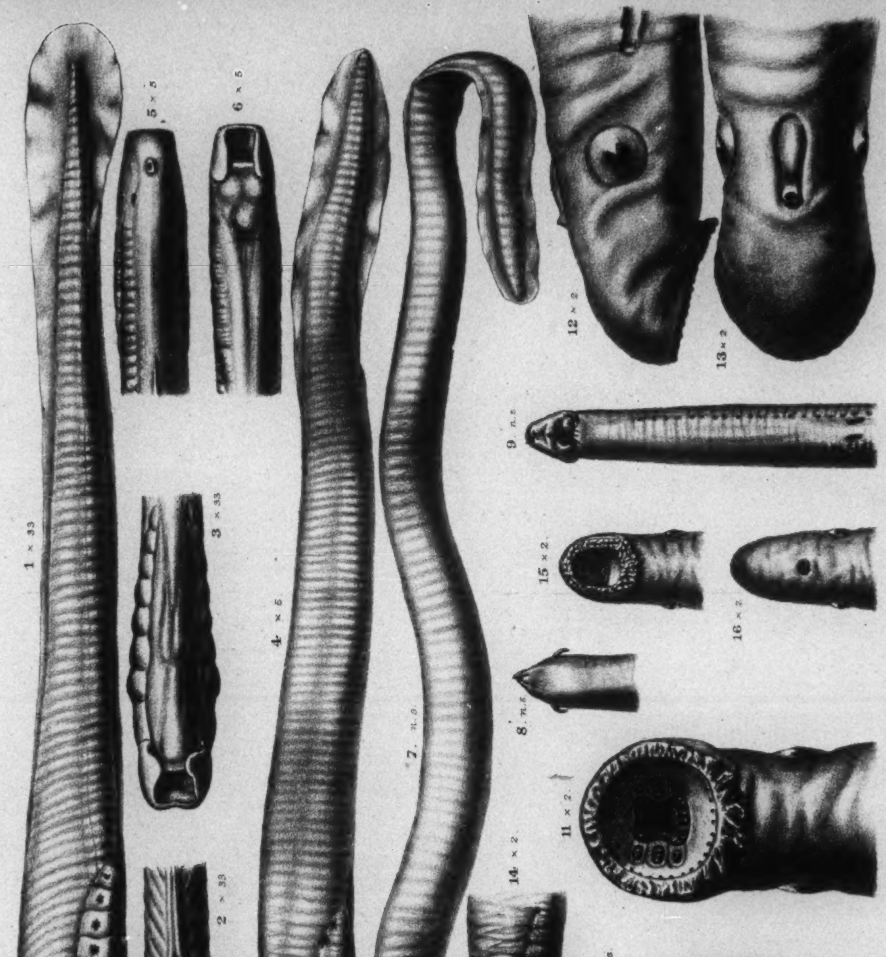
W.

WARD (H. M.). On the Morphology and Development of the Perithecium of Meliolia, a Genus of Tropical Epiphyllous Fungi, 583; description of plates, 597.

WILLIAMSON (W. C.). On the Organization of the Fossil Plants of the Coal-Measures.—Part XII., 459.—Psaronius Renaultii, 464; Zygosporites, 464; Calamites, 465; Lepidodendroid plants, 465; Halonia, 466; Sporocarpon, 469; Dadoxylon, 469; index to the plates, 471.

Z.

Zygosporites, 464 (see WILLIAMSON).

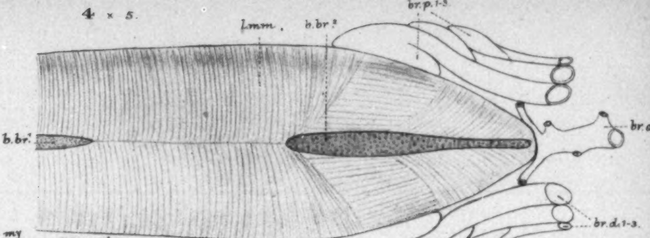


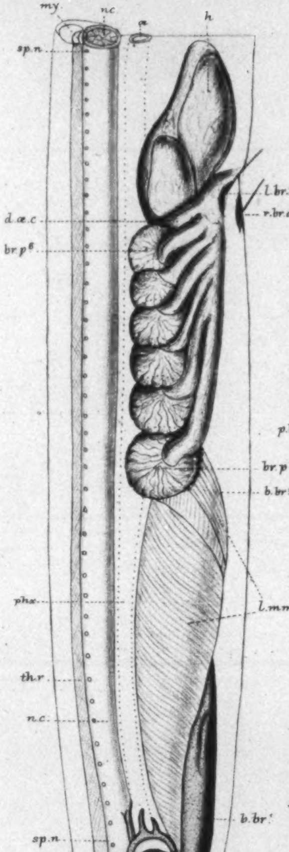
W. K. P. del. ad nat.
M. P. Parker lith. ad del.

MARSIPOBRANCH FISHES.

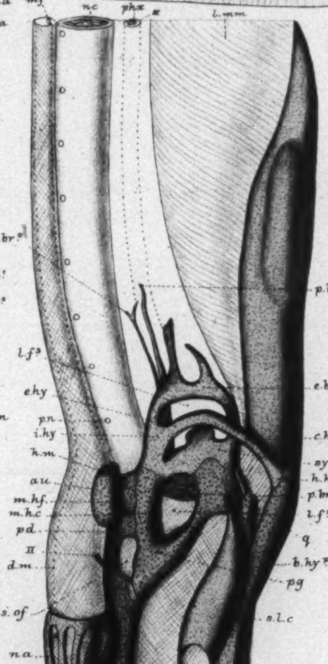
West Newman & Co. imp.

4 × 5.

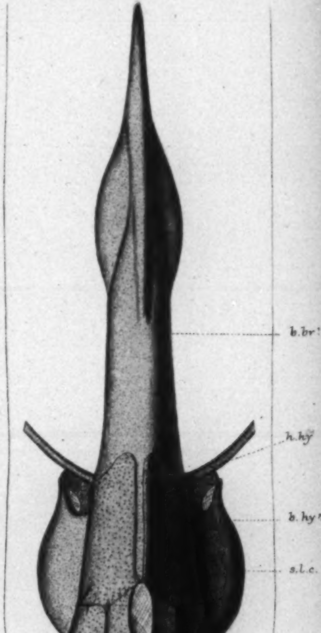




1 × 2½



2 × 5.

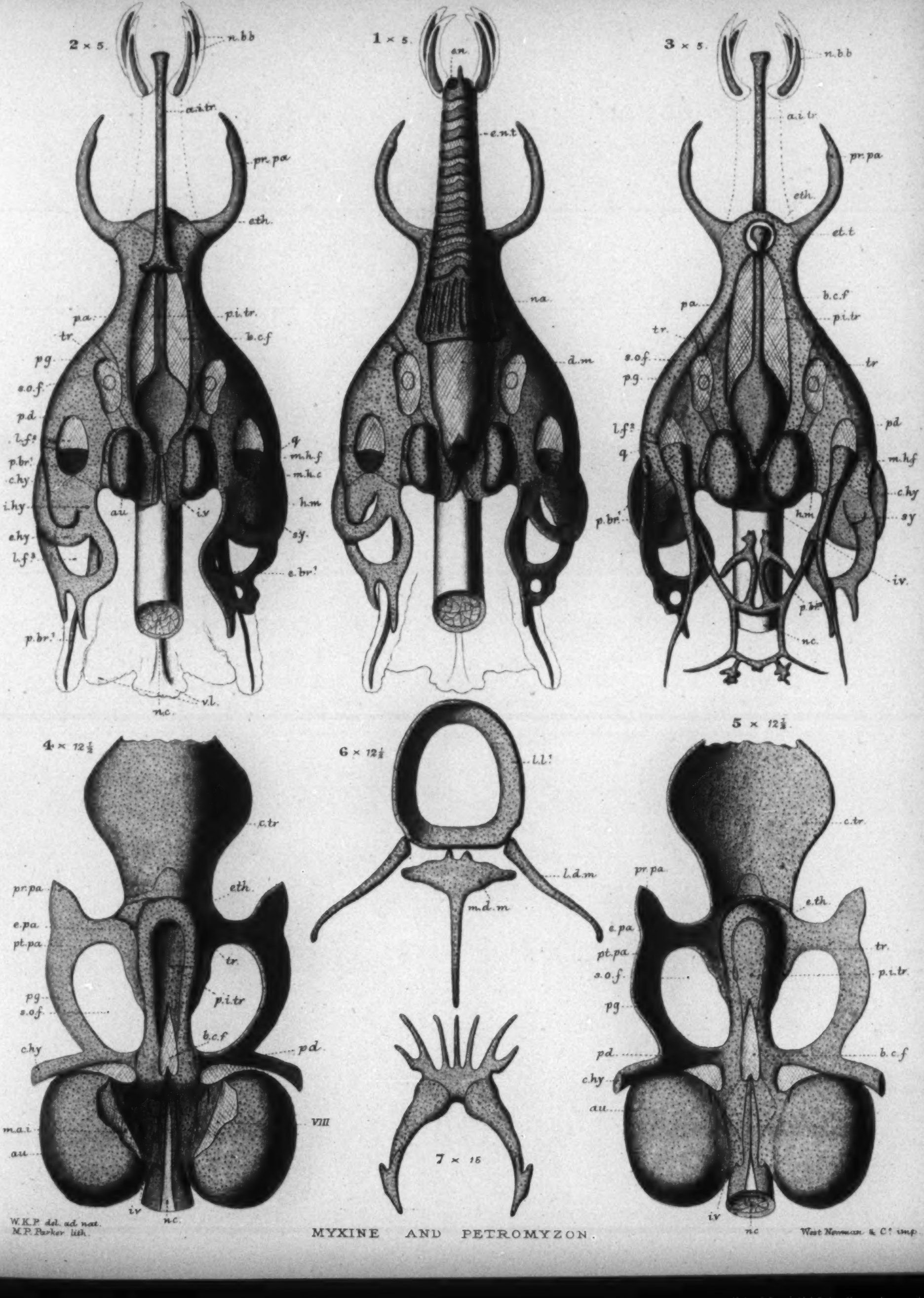


3 × 5

W.K.P. del. ad nat.
M.P. Parker lith.

MYXINE GLUTINOSA.

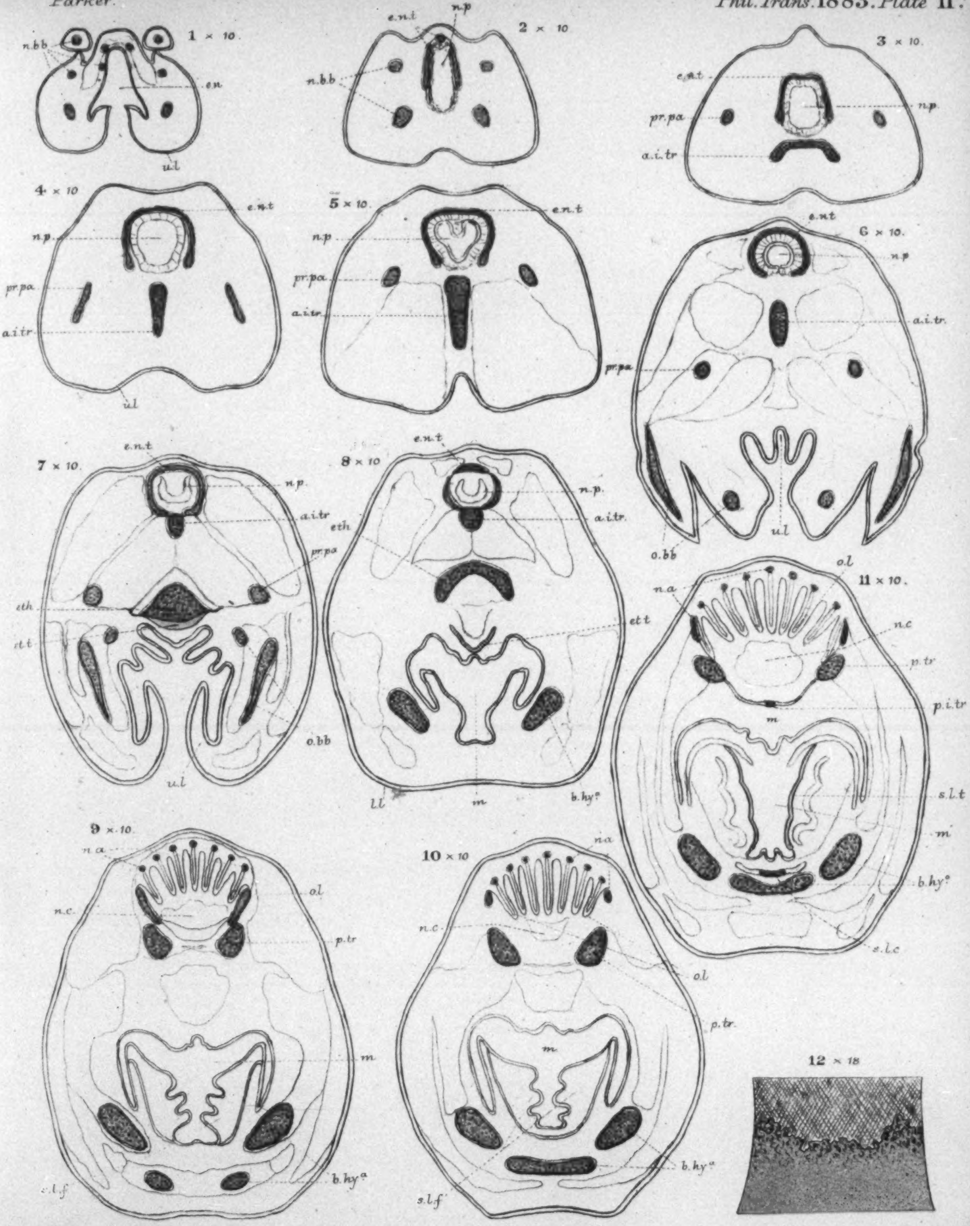
West Newman & Co. imp.



W.K.P. del. ad nat.
M.P. Parker lith.

MYXINE AND PETROMYZON.

West Newman & C° imp.



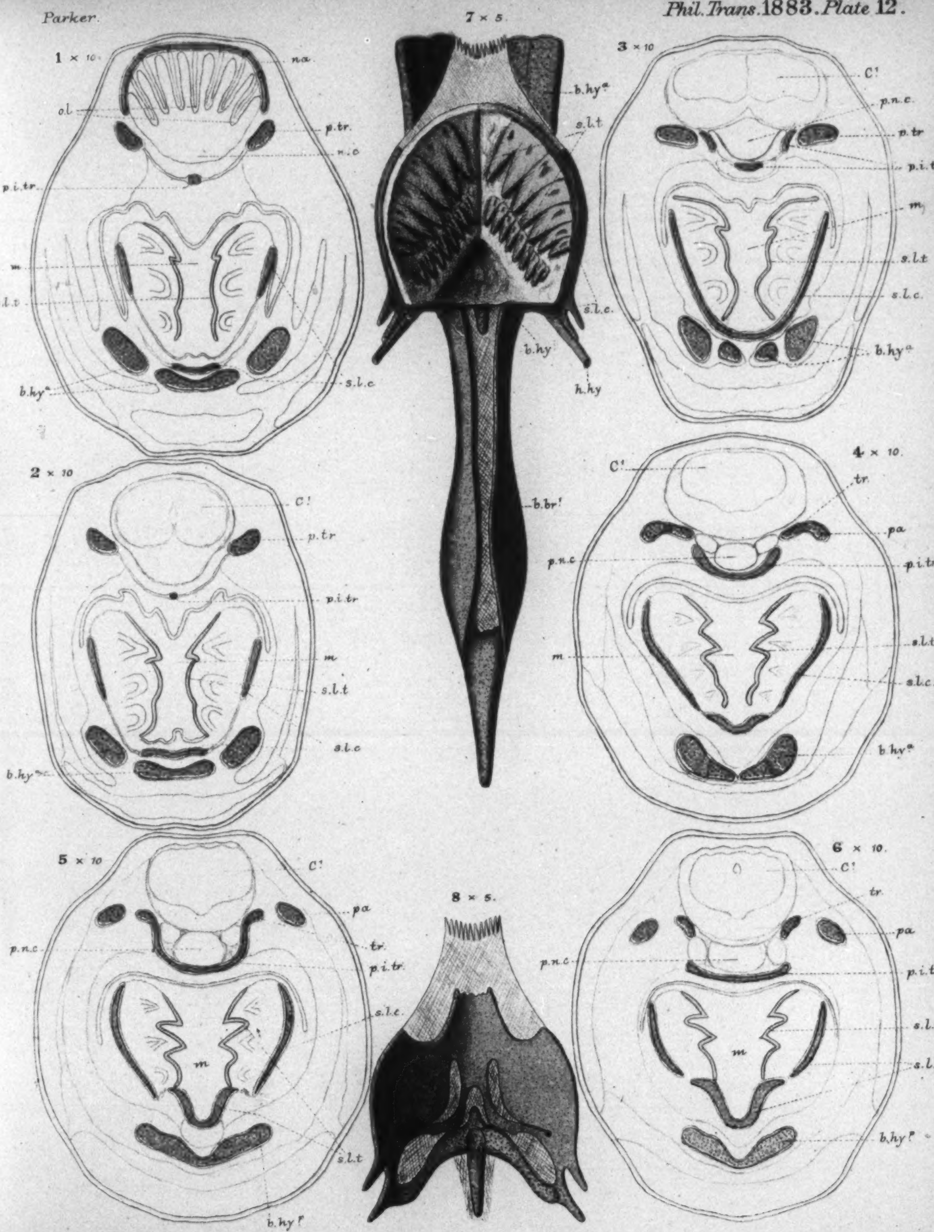
W.K.P. del. ad nat.
M.P.Parker lith. et del.

MYXINE GLUTUIOSA

West, Newman & Co. im.

Parker.

Phil. Trans. 1883. Plate 12.

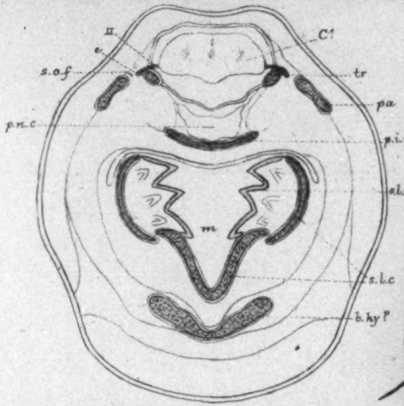


W.K.P. del. ad nat.
M.P. Parker lith. et del.

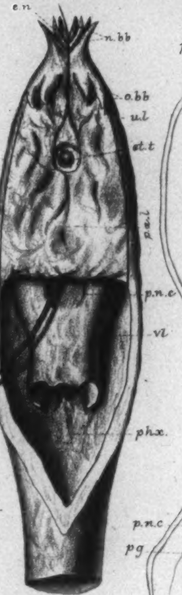
MYXINE GLUTINOSA.

West Newman & Co. imp

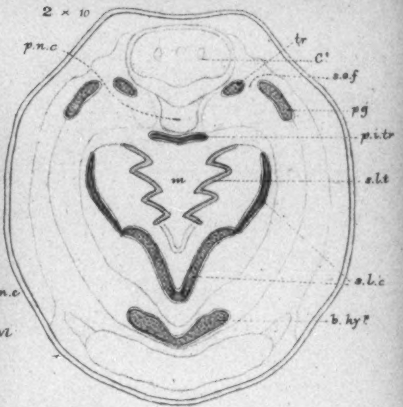
1 × 10.



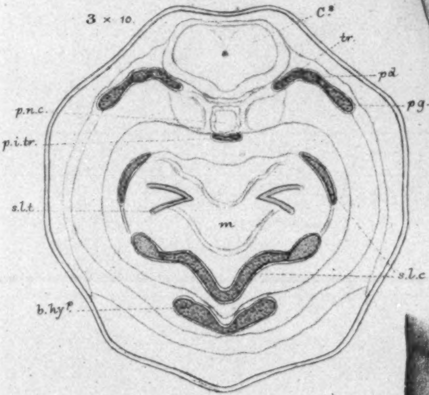
7 × 2½



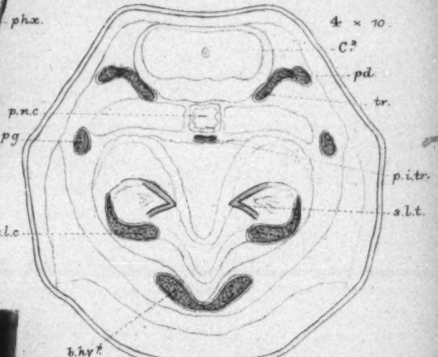
2 × 10



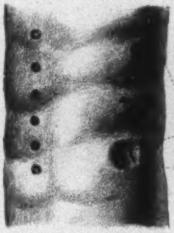
3 × 10.



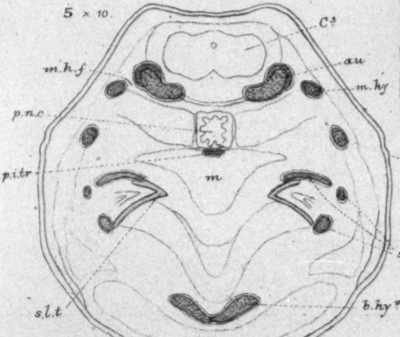
4 × 10.



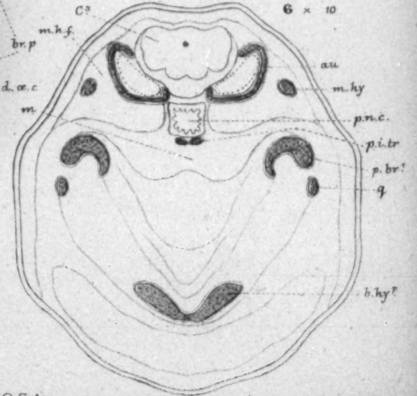
8 . ⅓ n.s.



5 × 10.



6 × 10

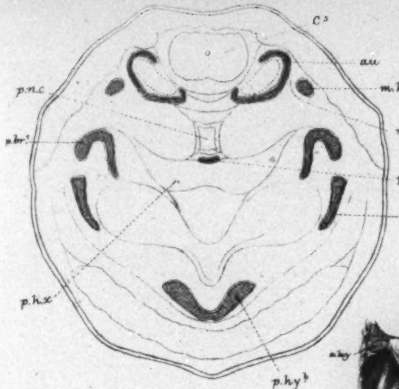


W.K.P. del. ad nat.
M.P. Parker lith. et del.

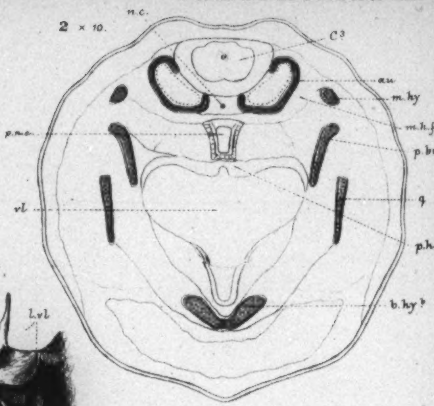
MYXINE GLUTINOSA.

West Newman & Co. imp.

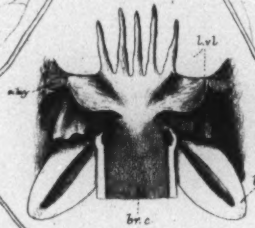
1 × 10



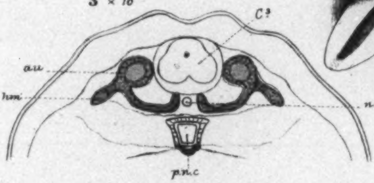
2 × 10.



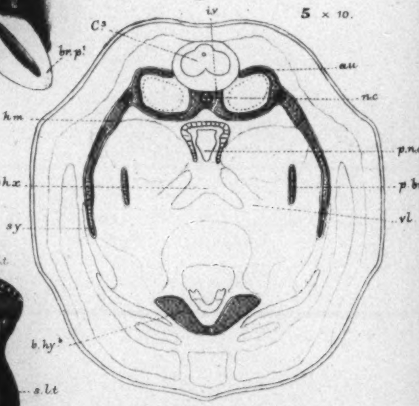
8 × 7½



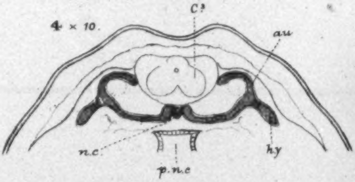
3 × 10



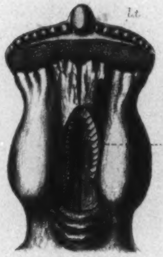
5 × 10.



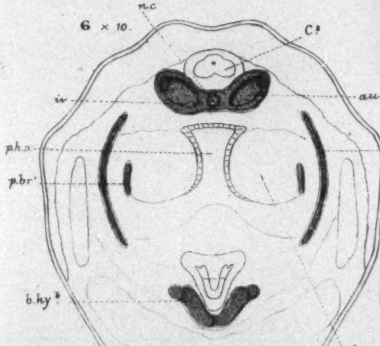
4 × 10.



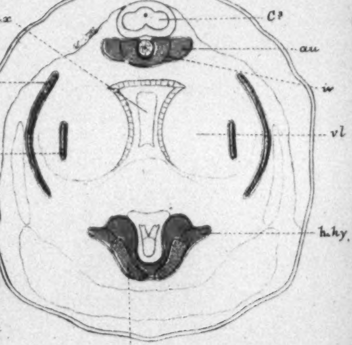
9 × 7½



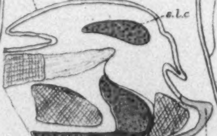
6 × 10.



7 × 10.



10 × 7½



W.K.P. del. ad nat.
M.P. Parker lith. et del.

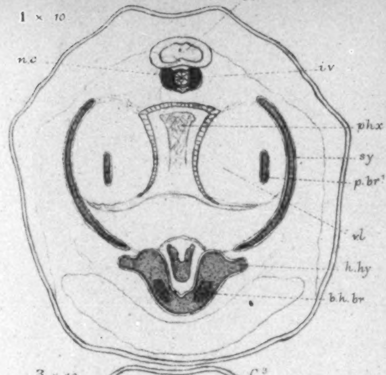
MYXINE AND PETROMYZON.

West Newman & Cº imp.

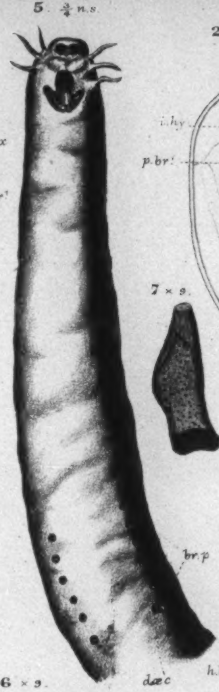
Parker

Phil. Trans. 1883. Plate 15.

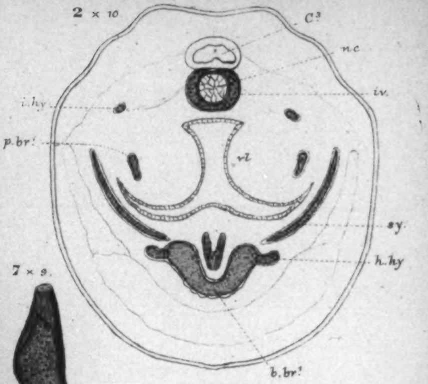
1 × 10



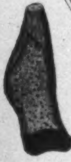
5. ¾ n.s.



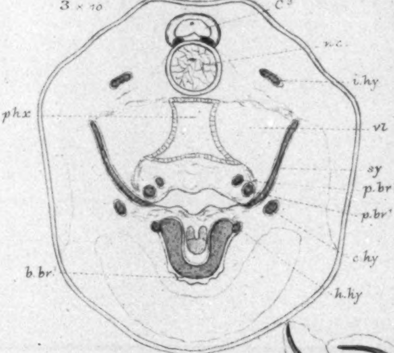
2 × 10



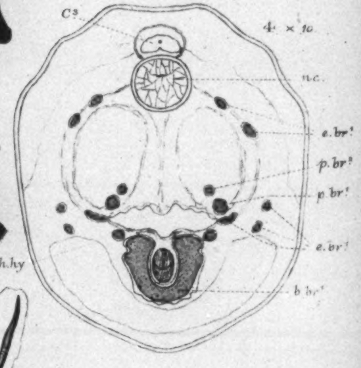
7 × 9.



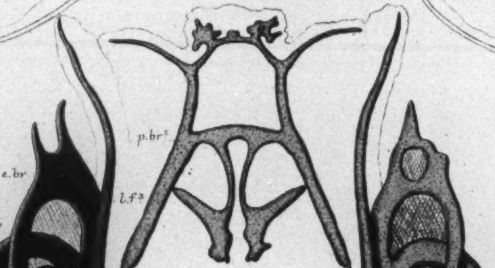
3 × 10



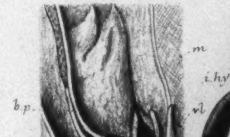
4 × 10



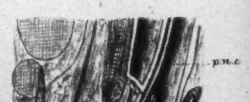
6 × 9.



8 × 4.



9 × 4.

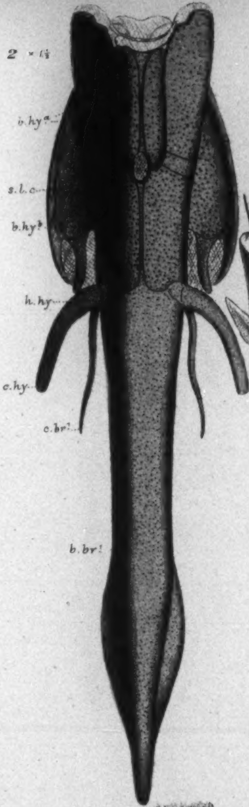


W.K.P. del. ad nat.
M.P. Parker lith. et del.

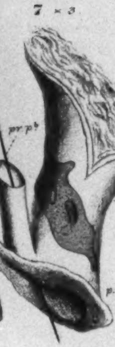
BDELLOSTOMA, MYXINE, AND PETROMYZON

West Newman & Co imp.

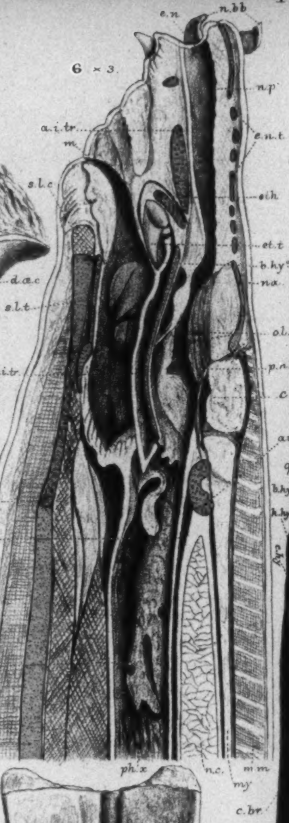
2 × 1½



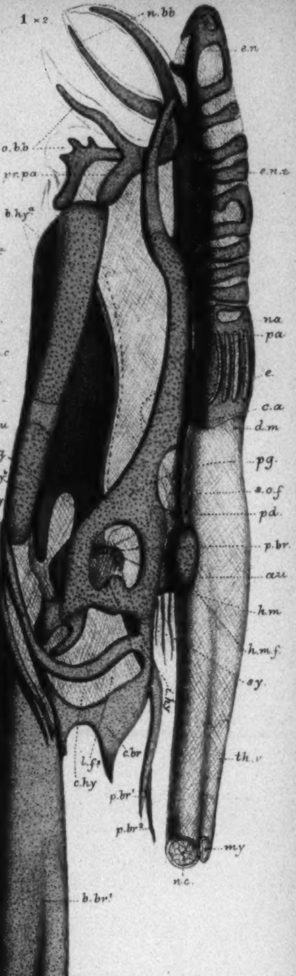
7 × 3



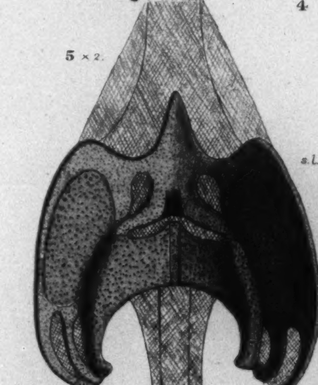
6 × 3



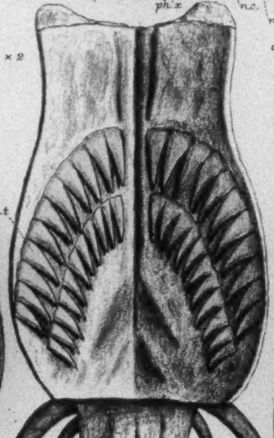
1 × 2



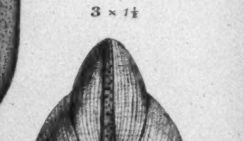
5 × 2



4 × 2



3 × 1½

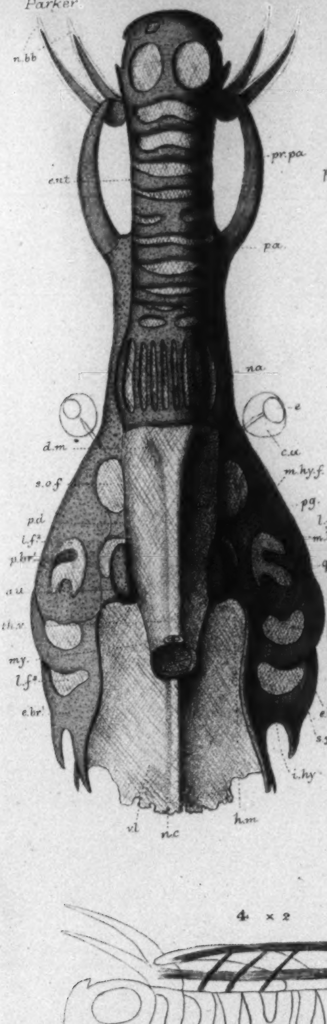


W.K.P. del. ad nat.
M.P. Parker lith.

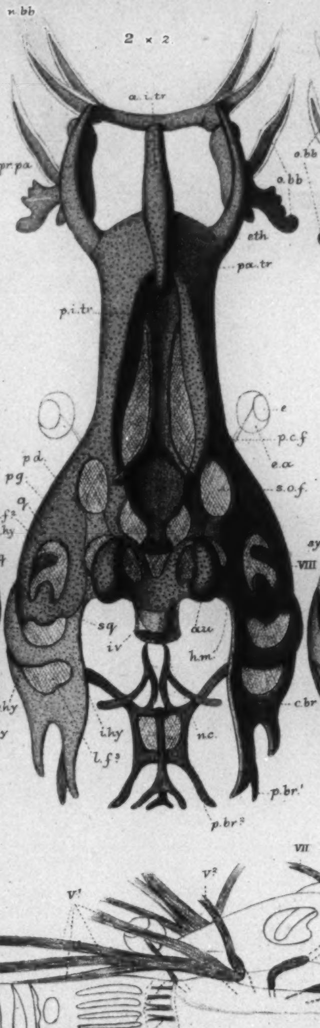
BDELLOSTOMA FORSTERI.

West Newman & Co imp.

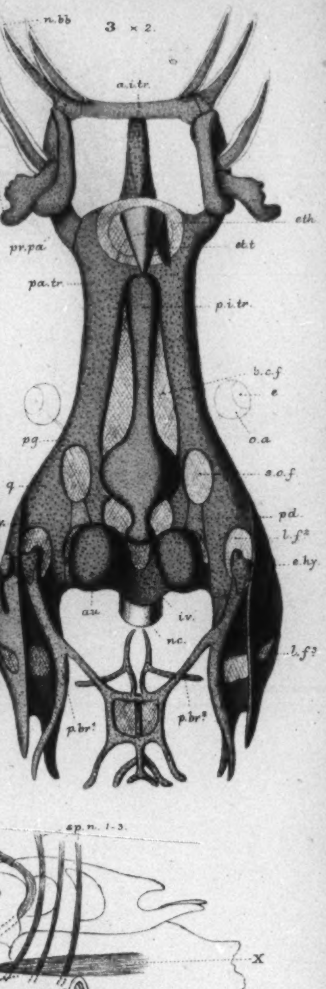
1 × 2.



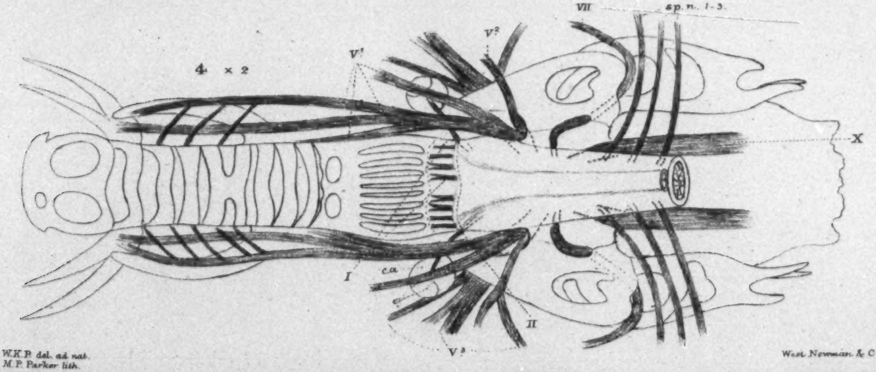
2 × 2.



3 × 2.



4 × 2



W.K.P. del. ad nat.
M.P. Parker lith.

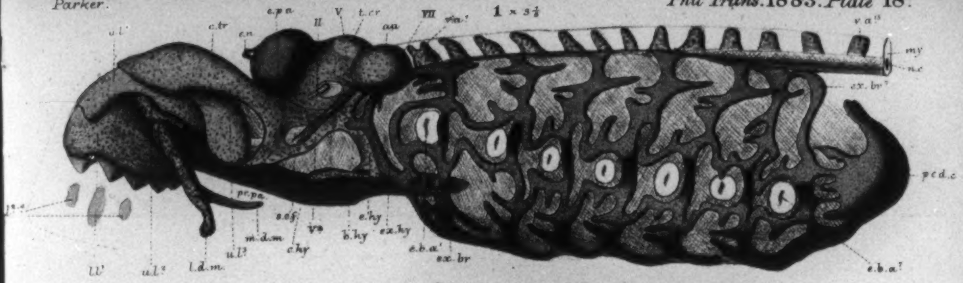
West Newman & Co imp.

BDELLOSTOMA FORSTERI.

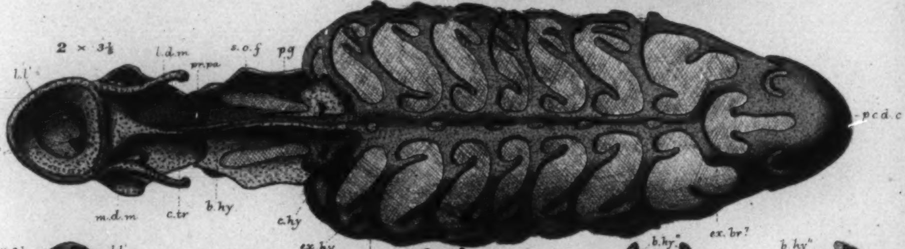
Parker.

Phil Trans. 1883. Plate 18.

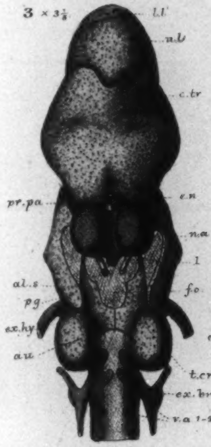
1 × 3½



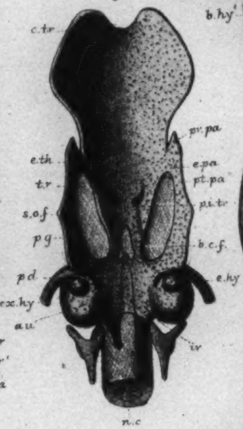
2 × 3½



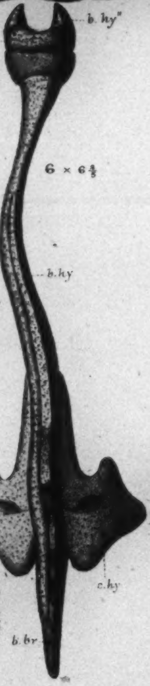
3 × 3½



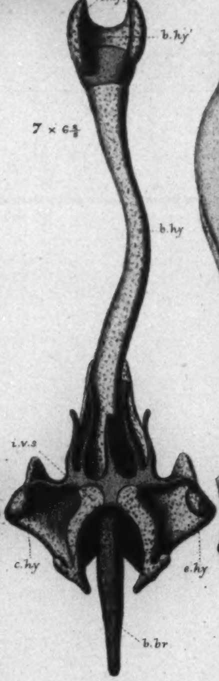
4 × 3½



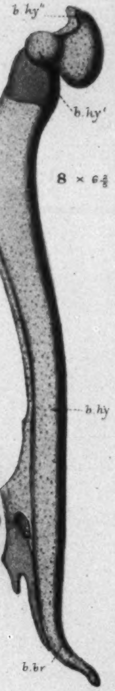
6 × 6⅗



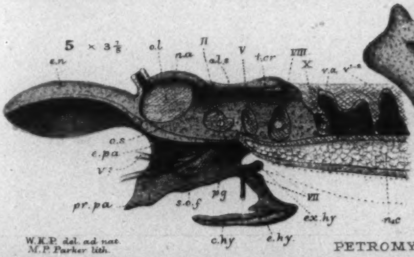
7 × 6⅗



8 × 6⅗



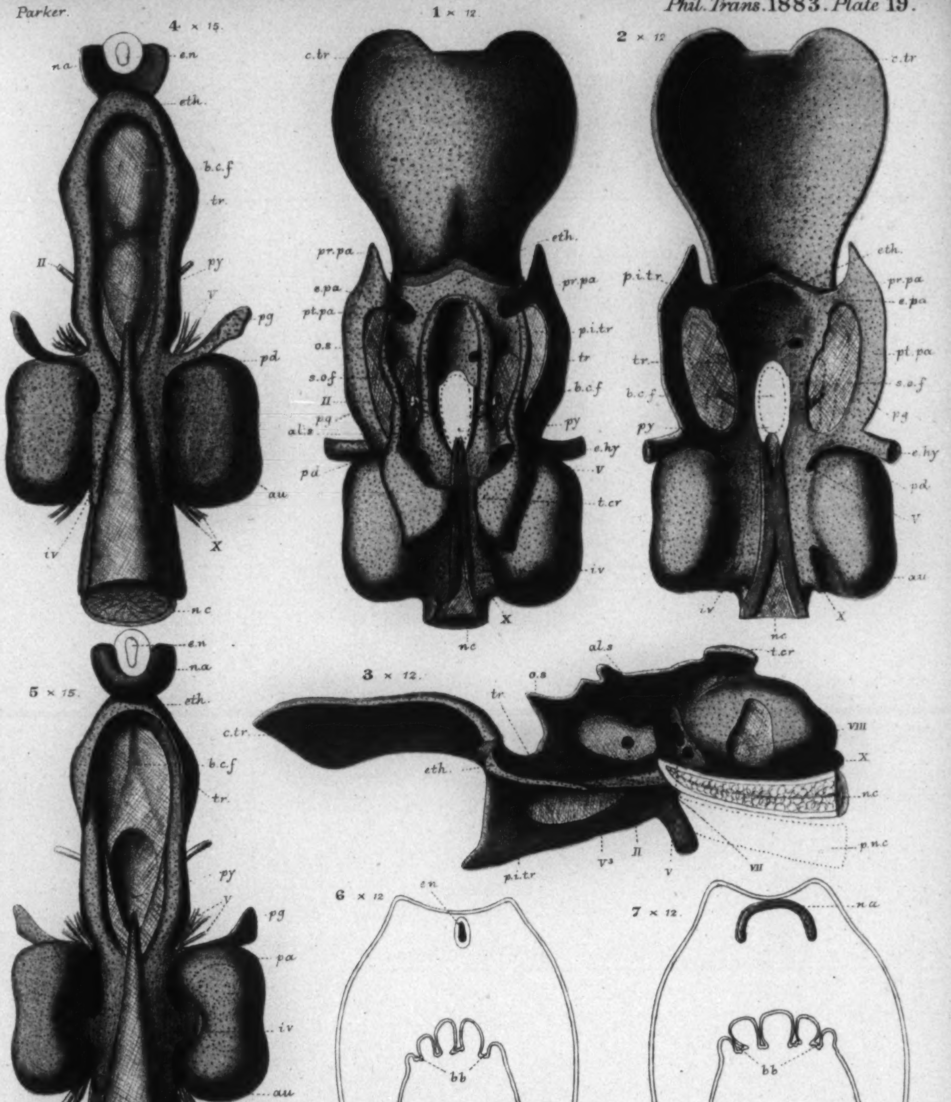
5 × 3½



W.K.P. del. ad nat.
M.P. Parker lith.

PETROMYZON MARINUS.

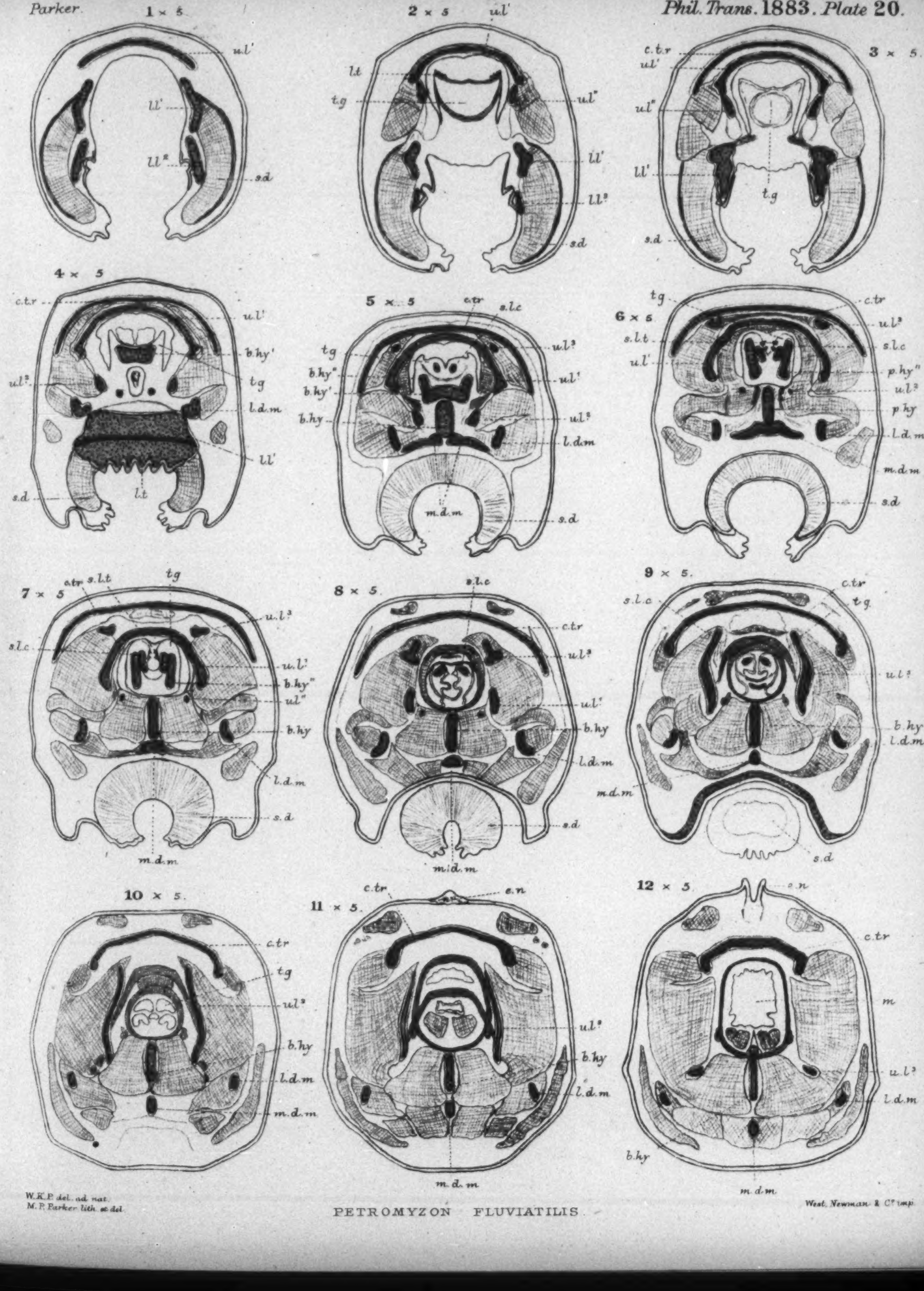
West Newman & Co imp.



PETROMYZON.

W.K.P. del. ad nat.
M.P. Parker lith. et del.

West Newman & Co imp.

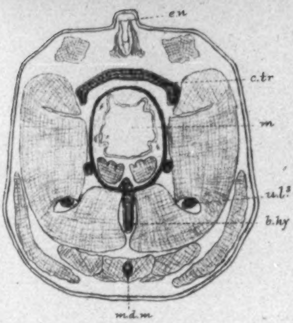


W.K.P. del. ad nat.
M.P. Parker lith. et del.

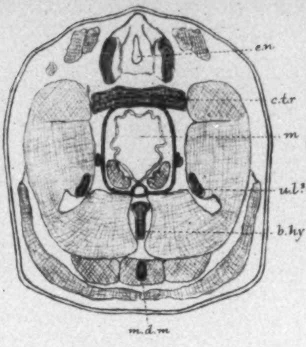
PETROMYZON FLUVIATILIS.

West, Newman & Co. imp.

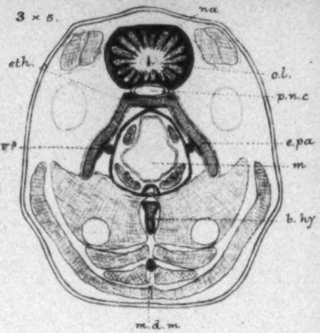
1 × 5.



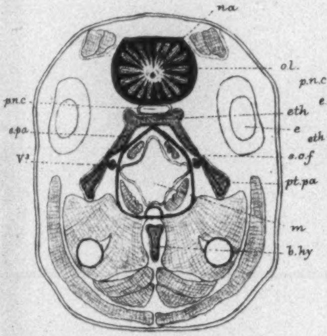
2 × 5.



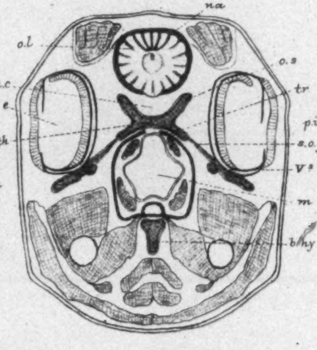
3 × 5.



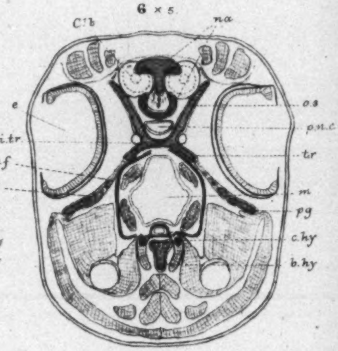
4 × 5.



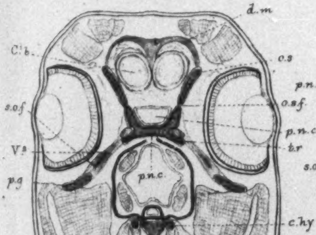
5 × 5.



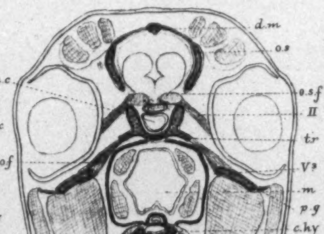
6 × 5.



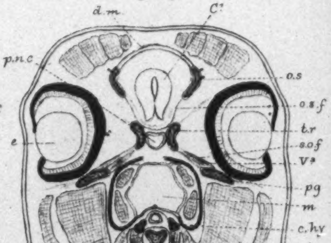
7 × 5.



8 × 5.



9 × 5.



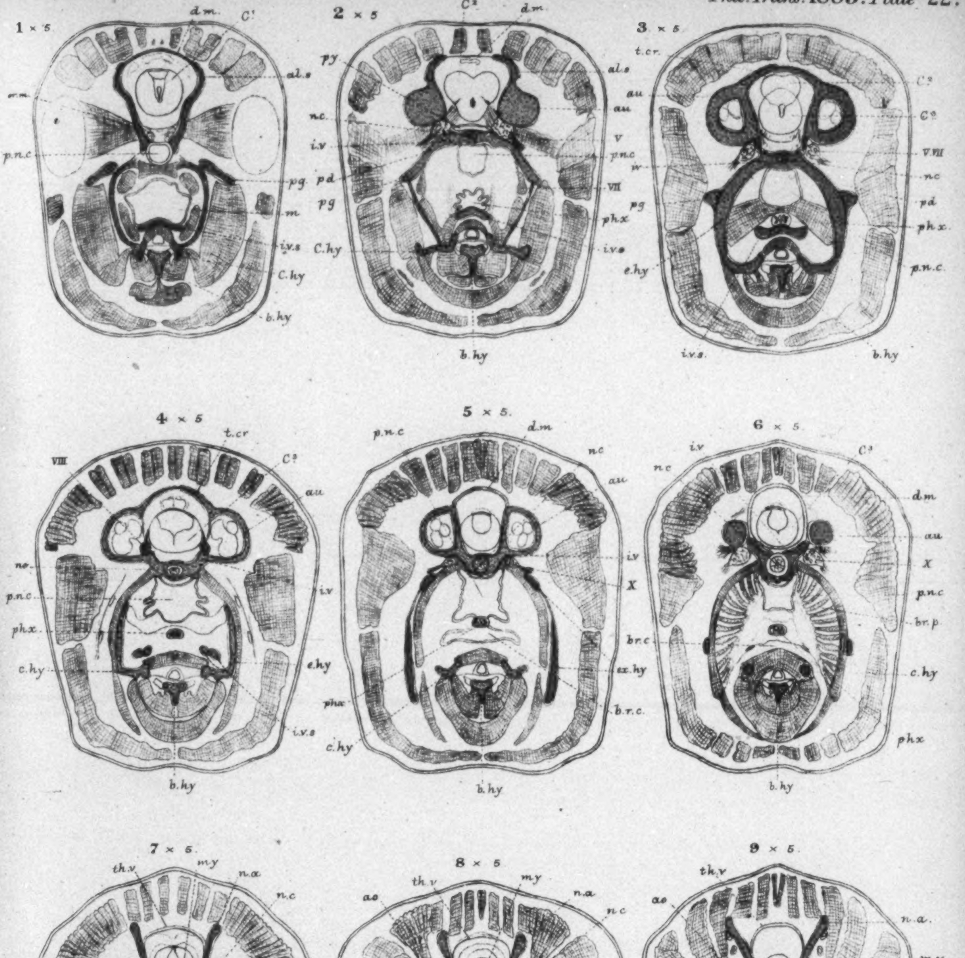
W.K.P. del. ad nat.
M.P. Parker lith. et del.

PETROMYZON FLUVIATILIS.

West Newman & Cº imp.

Parker.

Phil. Trans. 1883. Plate 22.



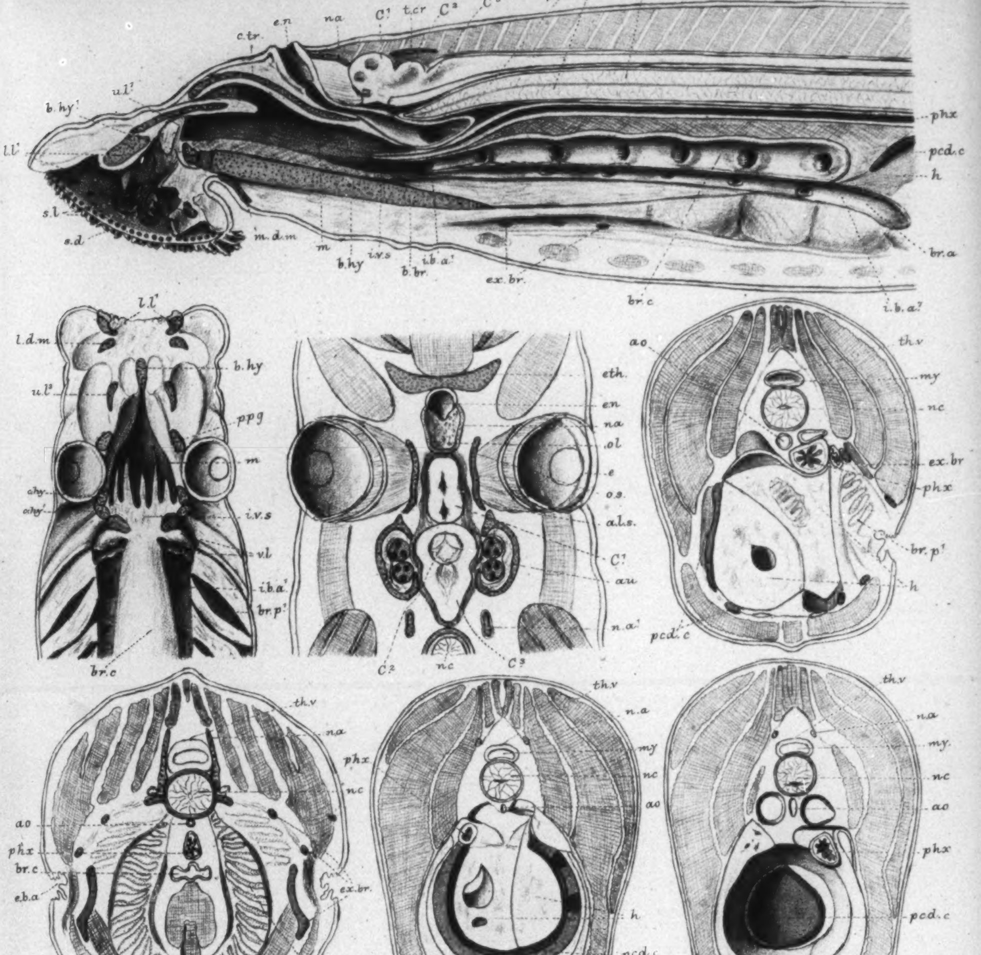
W.K.P. del. ad nat.
W. P. Parker lith. et del.

PETROMYZON FLUVIATILIS

West Newman & Cº imp.

Parker.

Phil. Trans. 1883. Plate 23.



W.K.P. del. ad nat.
M.P. Parker lith. et del.

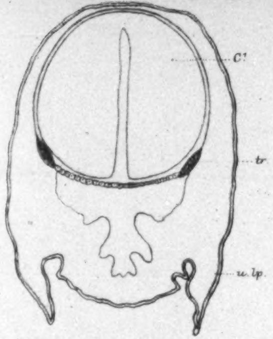
PETROMYZON FLUVIATILIS.

West Newman & Co. imp.

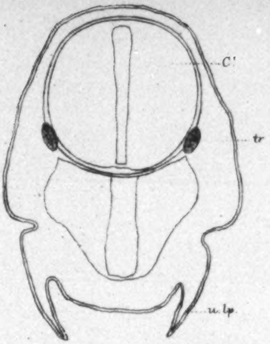
Parker

Phil. Trans. 1883. Plate 24.

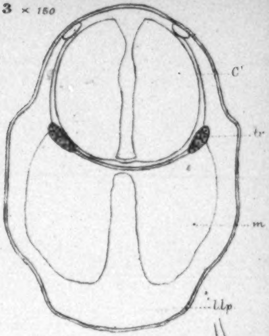
1 × 150



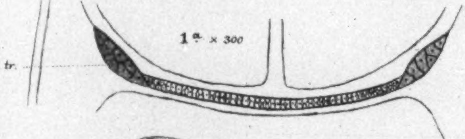
2 × 150



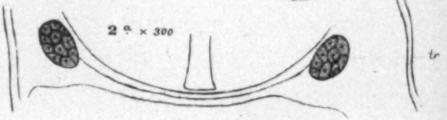
3 × 150



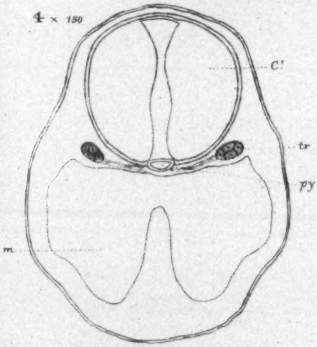
1ª × 300



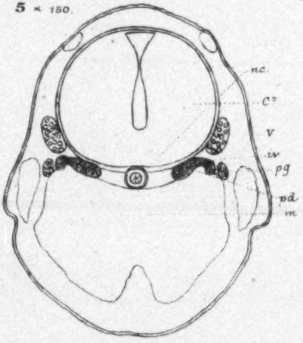
2ª × 300



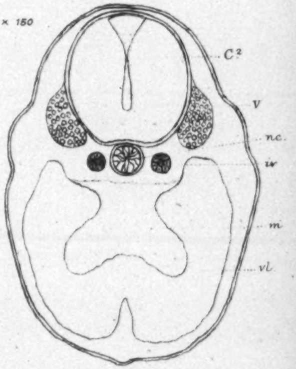
4 × 150



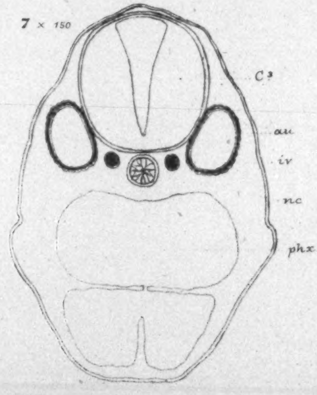
5 × 150



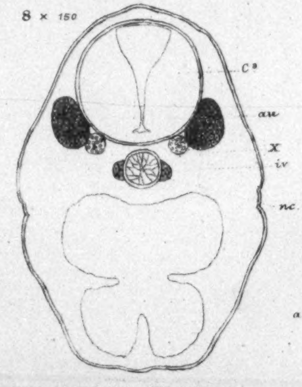
6 × 150



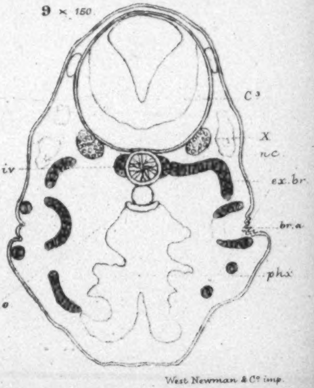
7 × 150



8 × 150



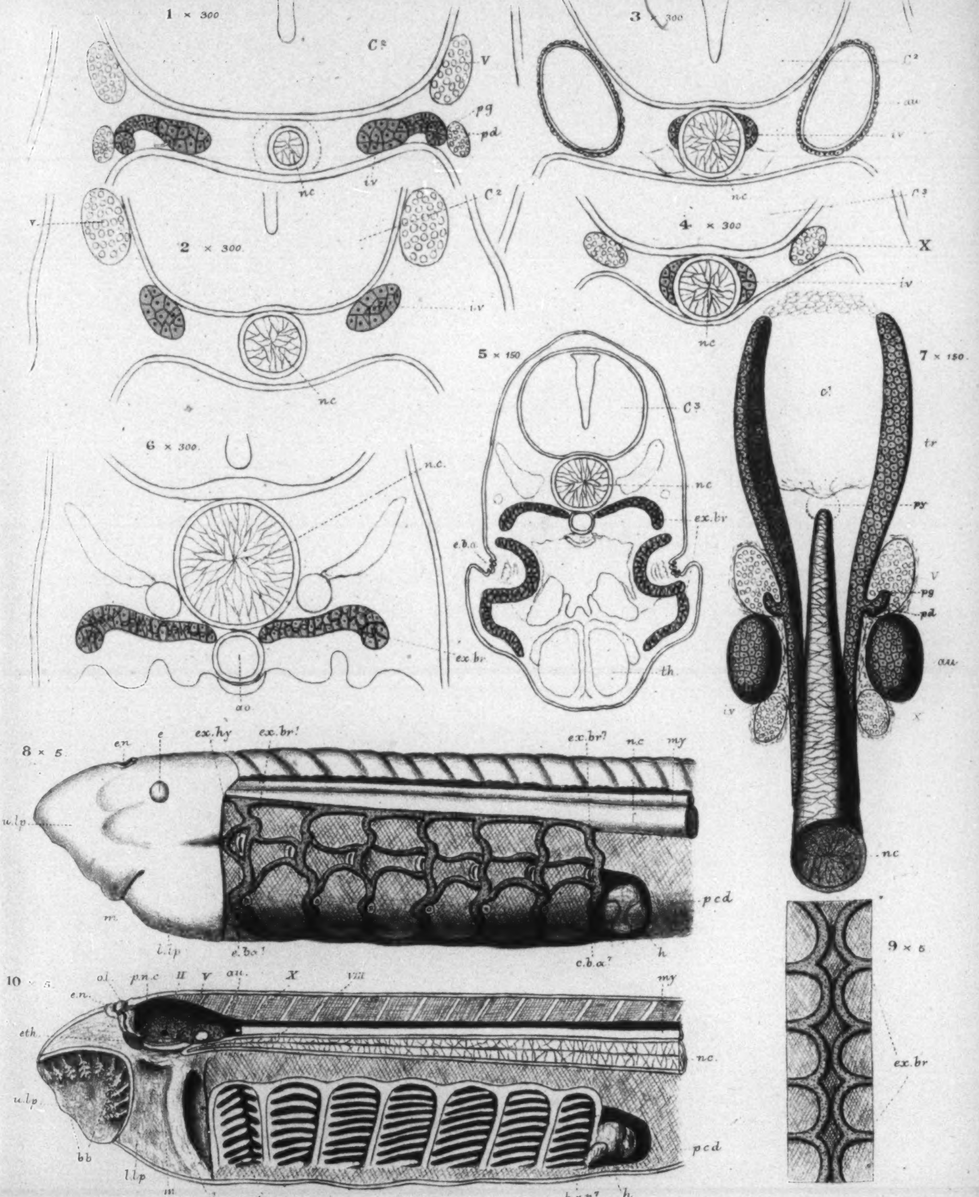
9 × 150



W. K. P. del. ad nat.
M. P. Parker lith.

PETROMYZON PLANERI

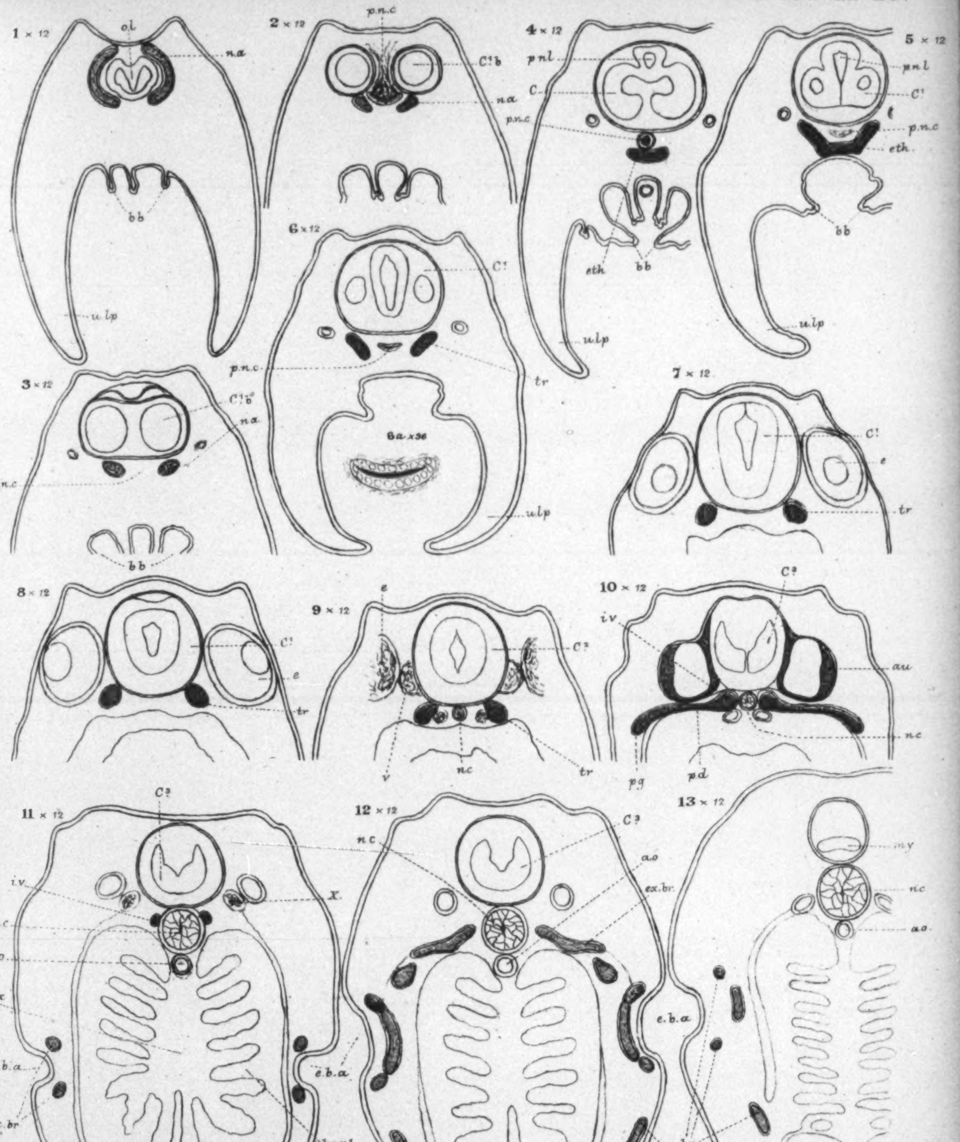
West Newman & Cº imp.



W.K.P. del. ad nat.
M.P. Parker lith. et del.

PETROMYZON.

West Newman & Co. imp.



PETROMYZON FLUVIATILIS.

W.K.P. del. ad nat.
M.P. Parker lith. et del.

West Newman & Co. imp.

Fig. 1.

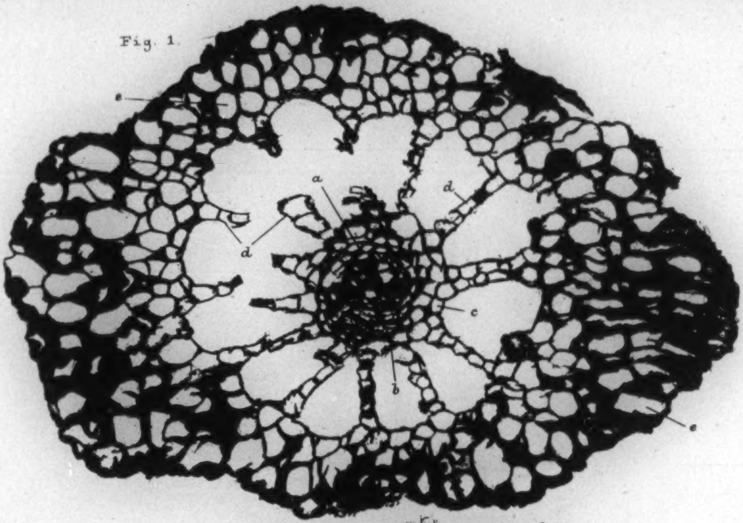
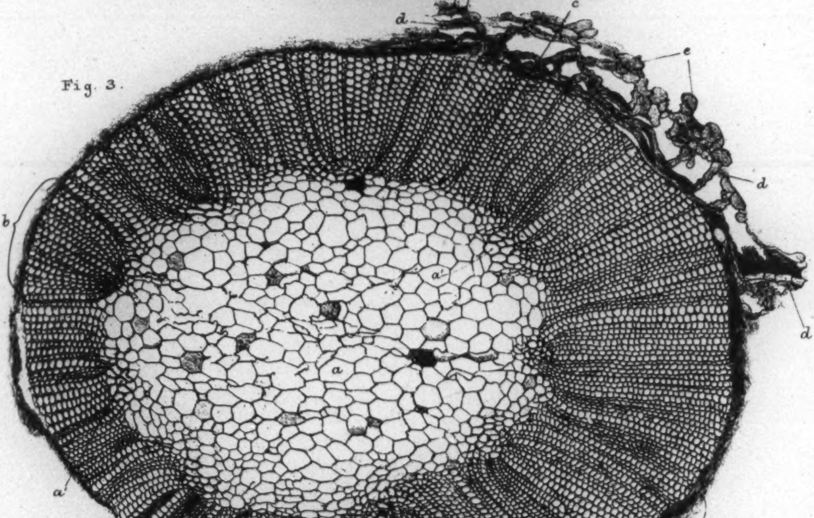


Fig. 3.



W. C. Williamson, Del.

Whiteman & Bass Photo-Litho London

Fig. 2.

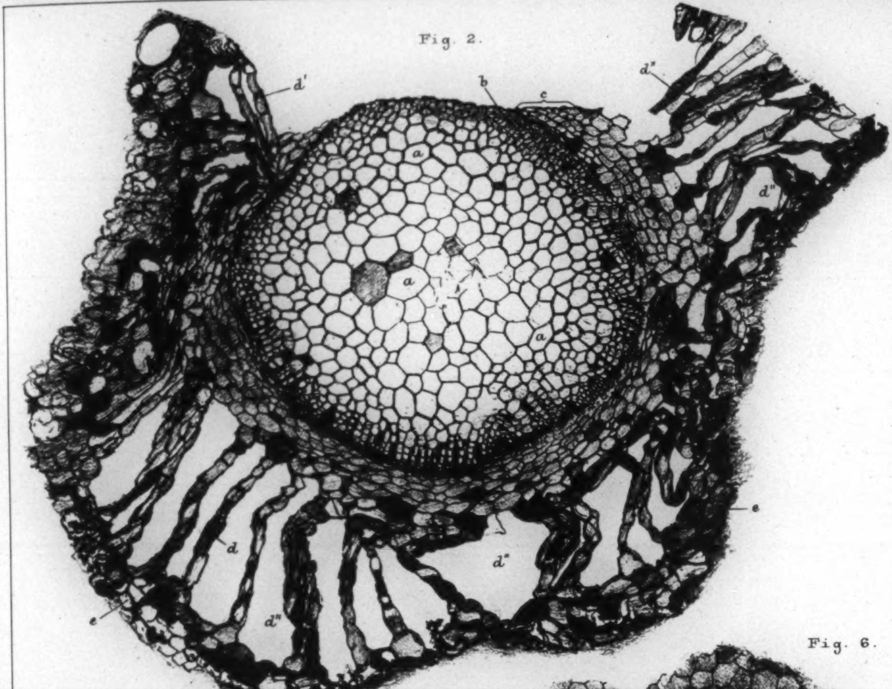


Fig. 6.

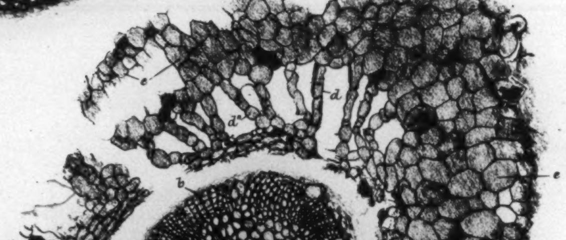


Fig. 9.

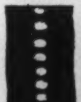
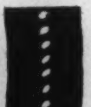


Fig. 8.



W. C. Williamson, Del.

Whiteman & Bass, Photo-Litho' London.

Fig. 12.

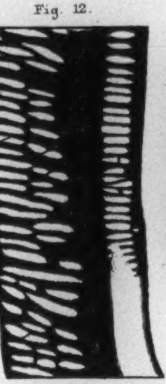


Fig. 13.

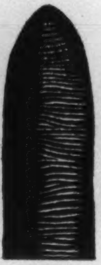


Fig. 7.

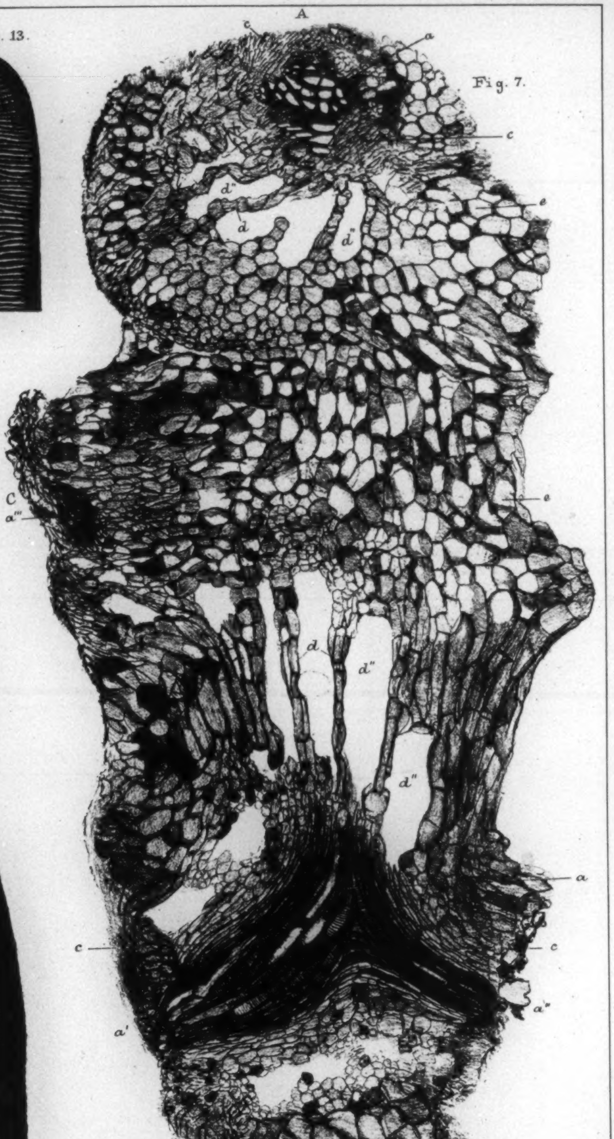


Fig. 10.

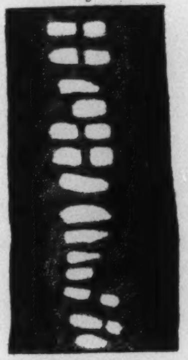
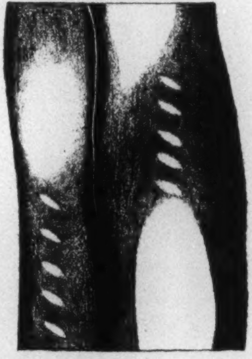


Fig. 11.



W. C. Williamson, Del.

Whiteman & Bass, Photo-Litho' London.

Fig. 5.

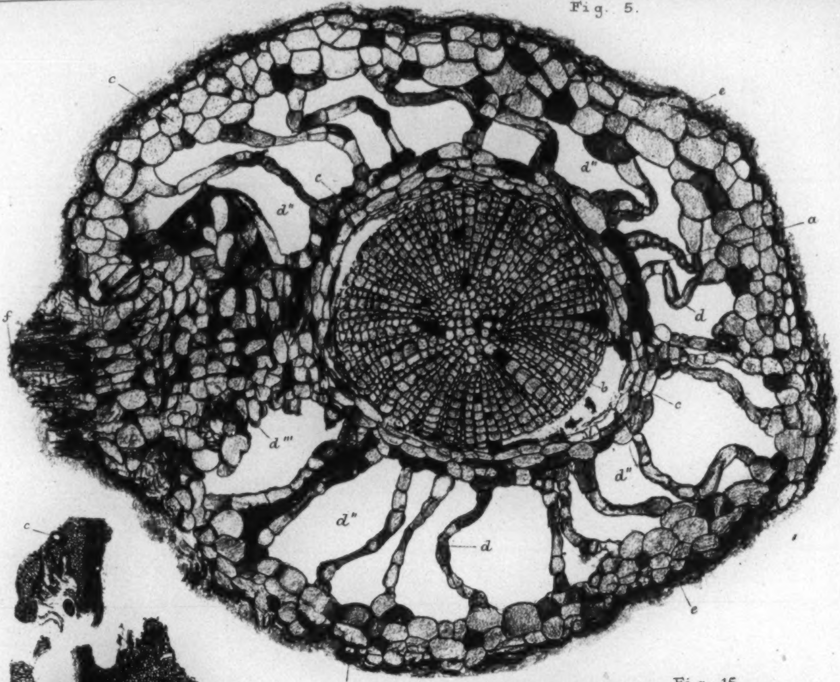


Fig. 16.

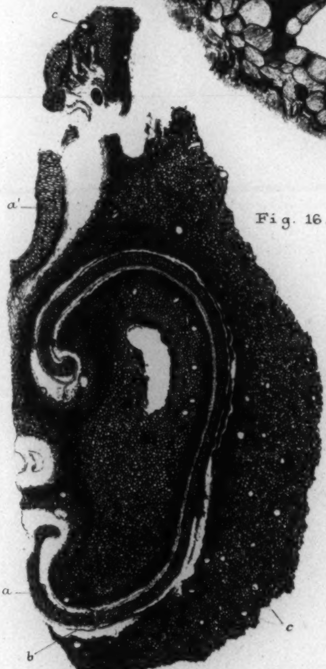
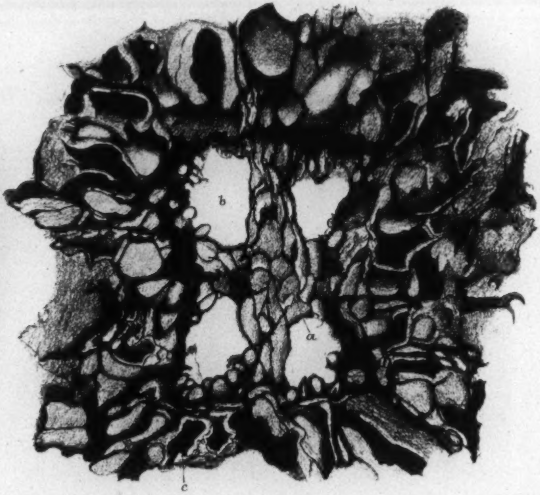


Fig. 15.



W. C. Williamson, Del.

Whitman & Bass, Photo-Litho. London

Fig. 4

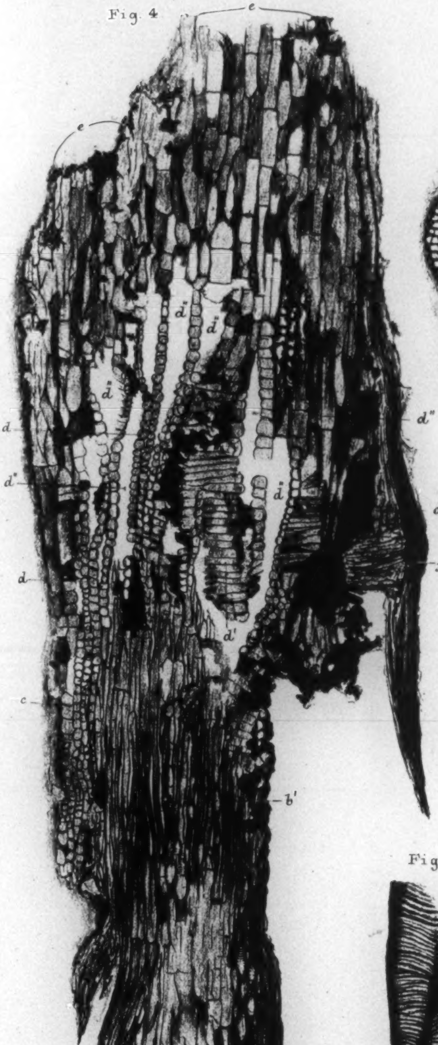


Fig. 27.

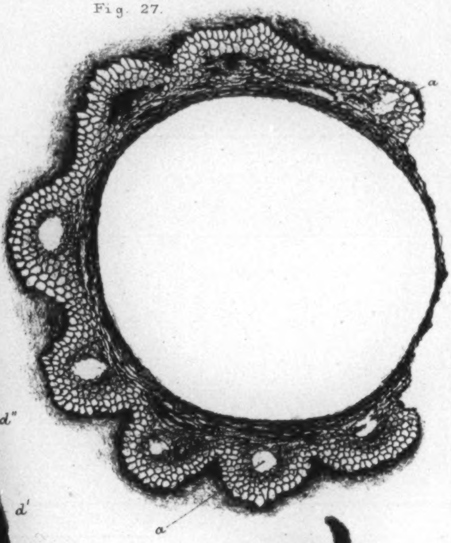


Fig. 14.

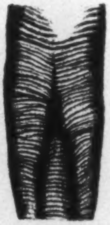
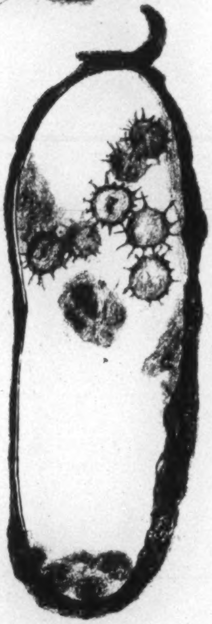


Fig. 17.



W. C. Williamson, Del.

Whiteman & Bass, Photo-Litho. London.

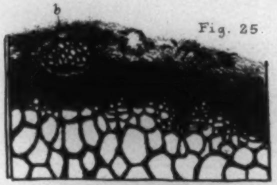


Fig. 25.

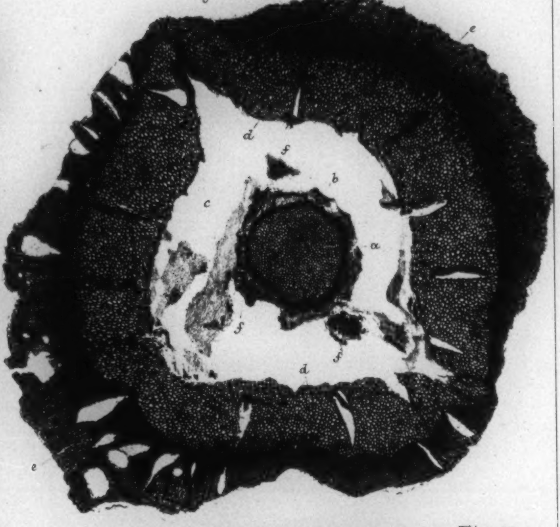


Fig. 21.

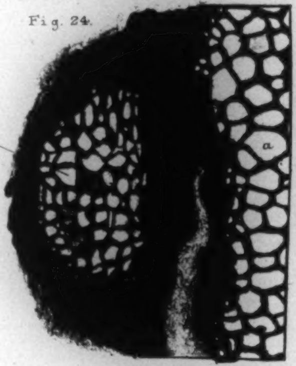


Fig. 24.

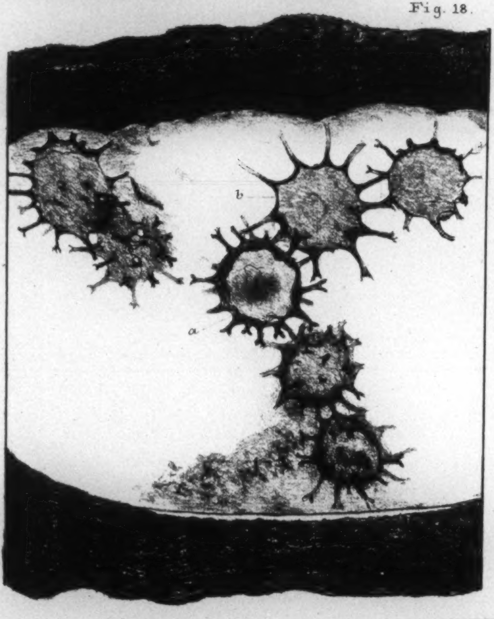


Fig. 18.

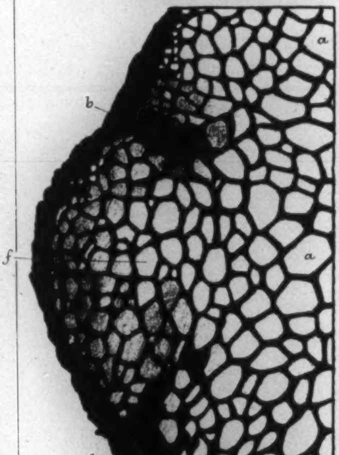


Fig. 22.

W. C. Williamson, Del.

Whiteman & Bass, Photo-Litho. London

Fig. 19.

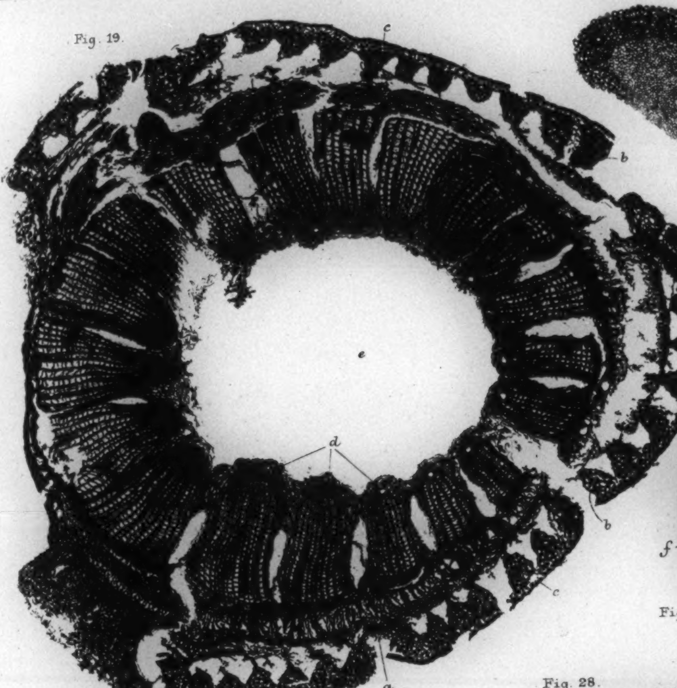


Fig. 29.

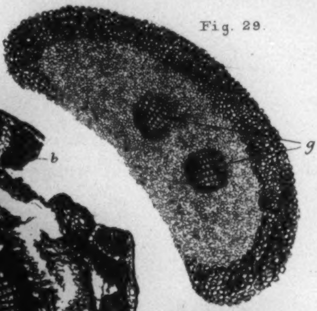


Fig. 23.

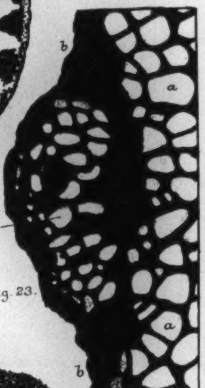


Fig. 20.

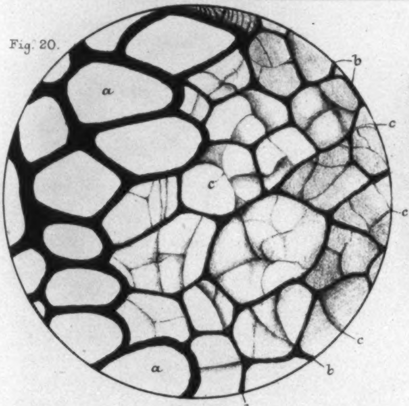
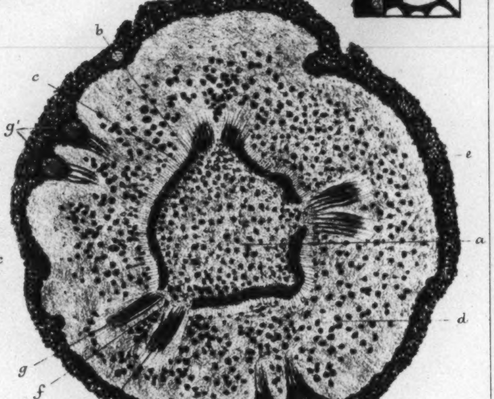
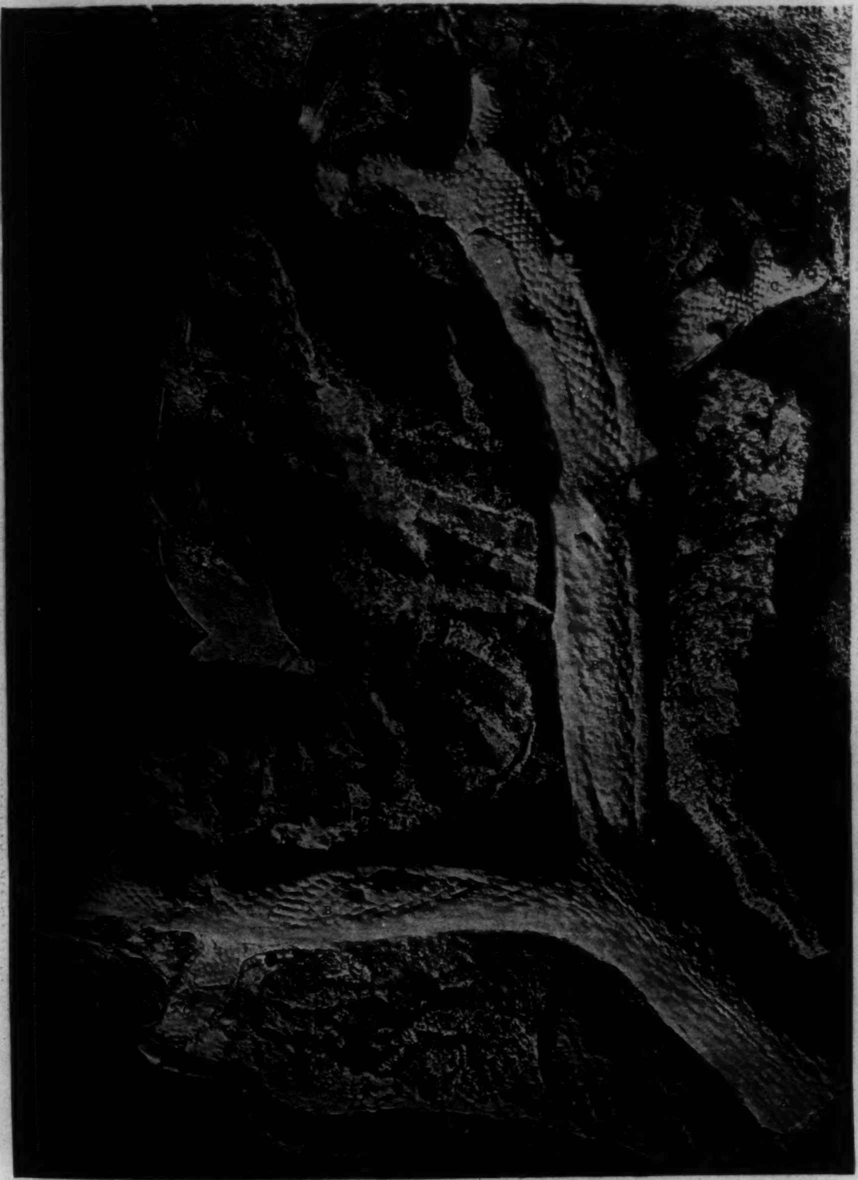


Fig. 28.

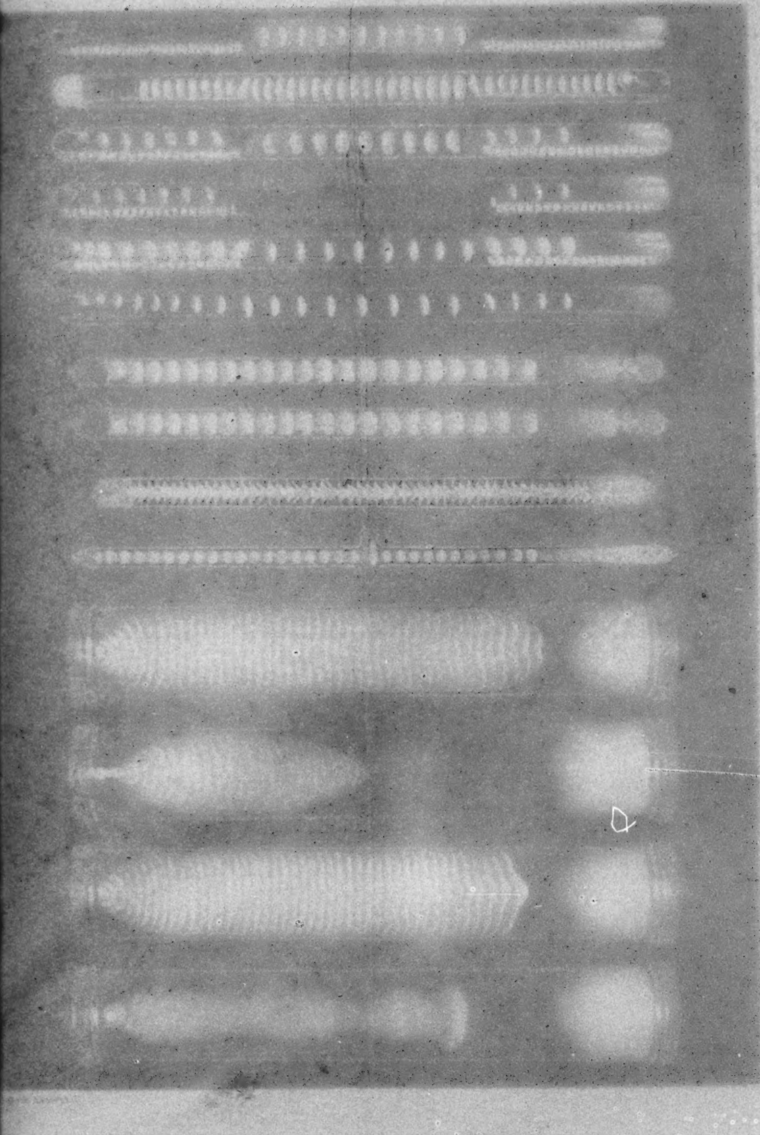


W. C. Williamson, Del.

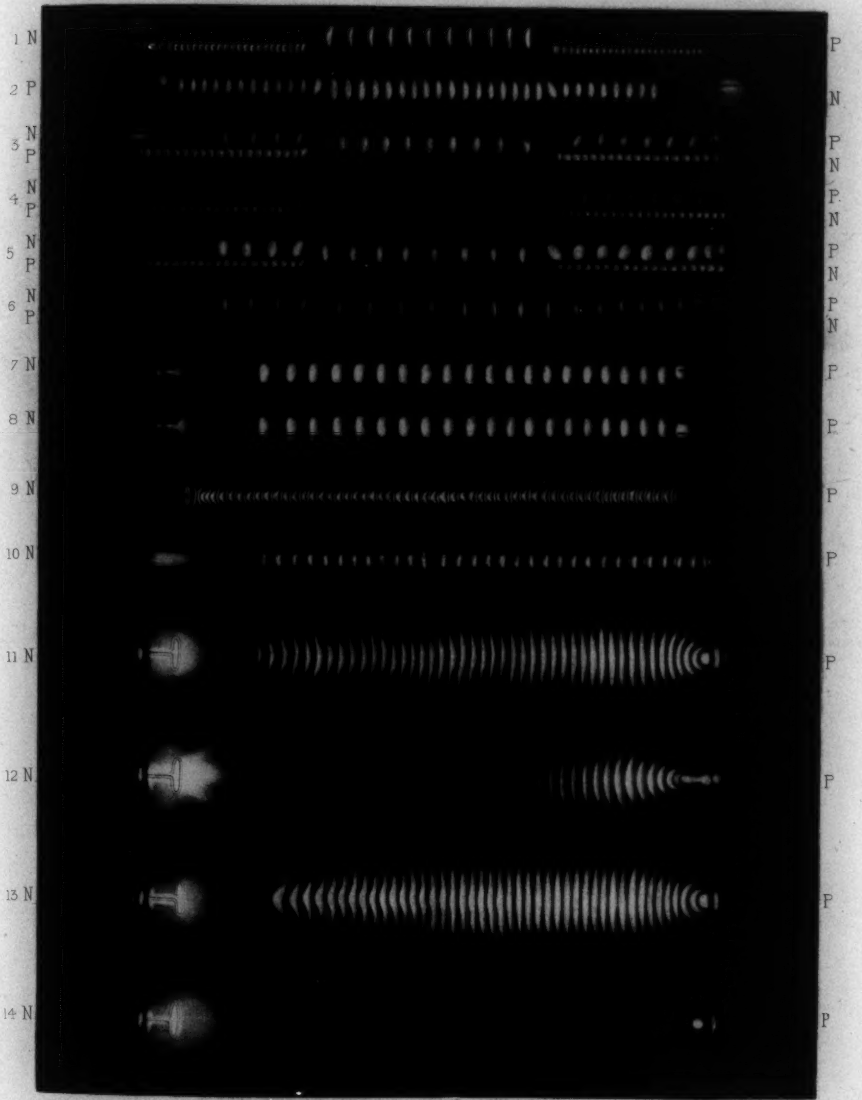
Whiteman & Bass, Photo-Litho. London.



PRINTED BY THE PHOTOMECHANICAL PRINTING COMPANY, 1c, LANSDOWNE ROAD, TOTTENHAM.

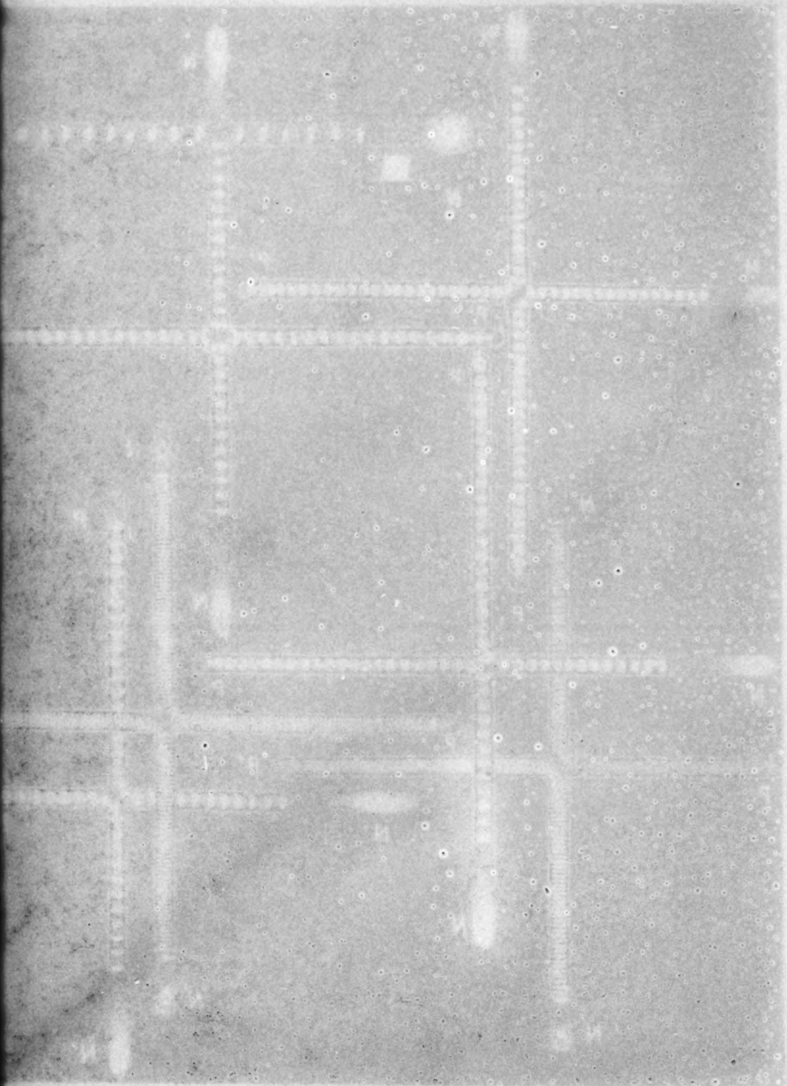


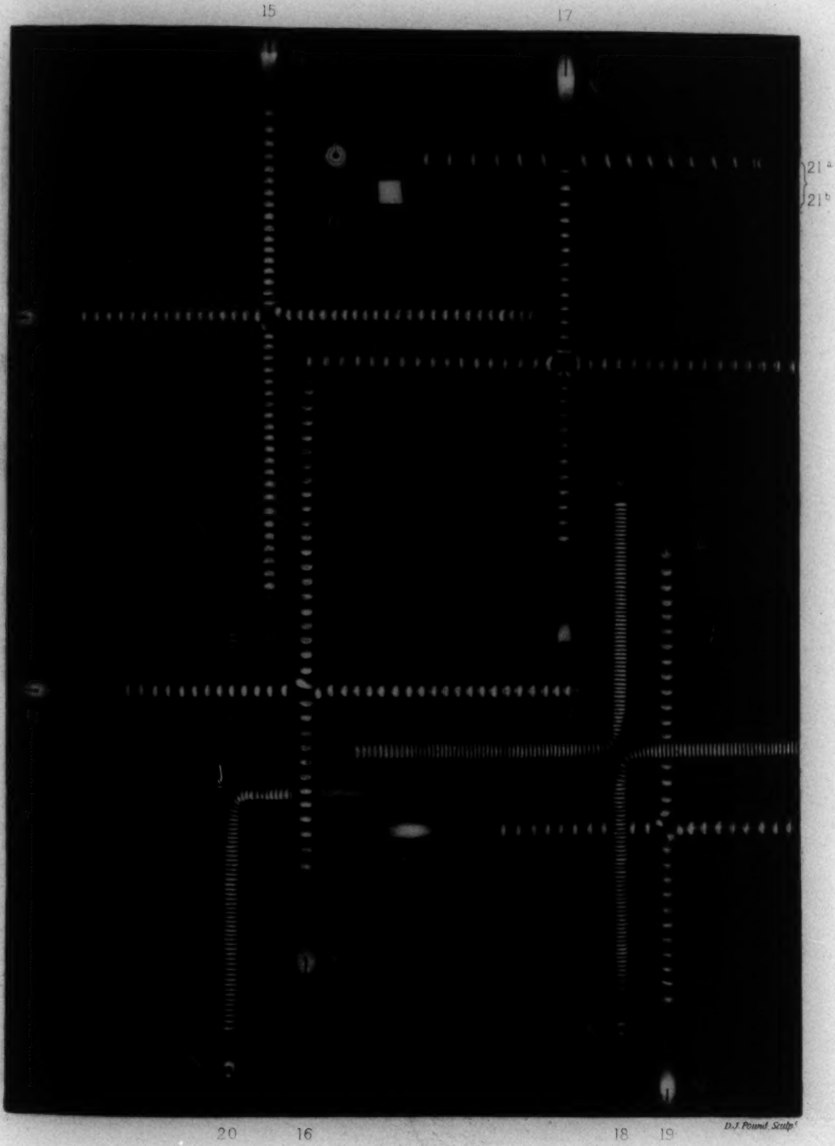
[illegible]



D. J. Pound. Sculp^t

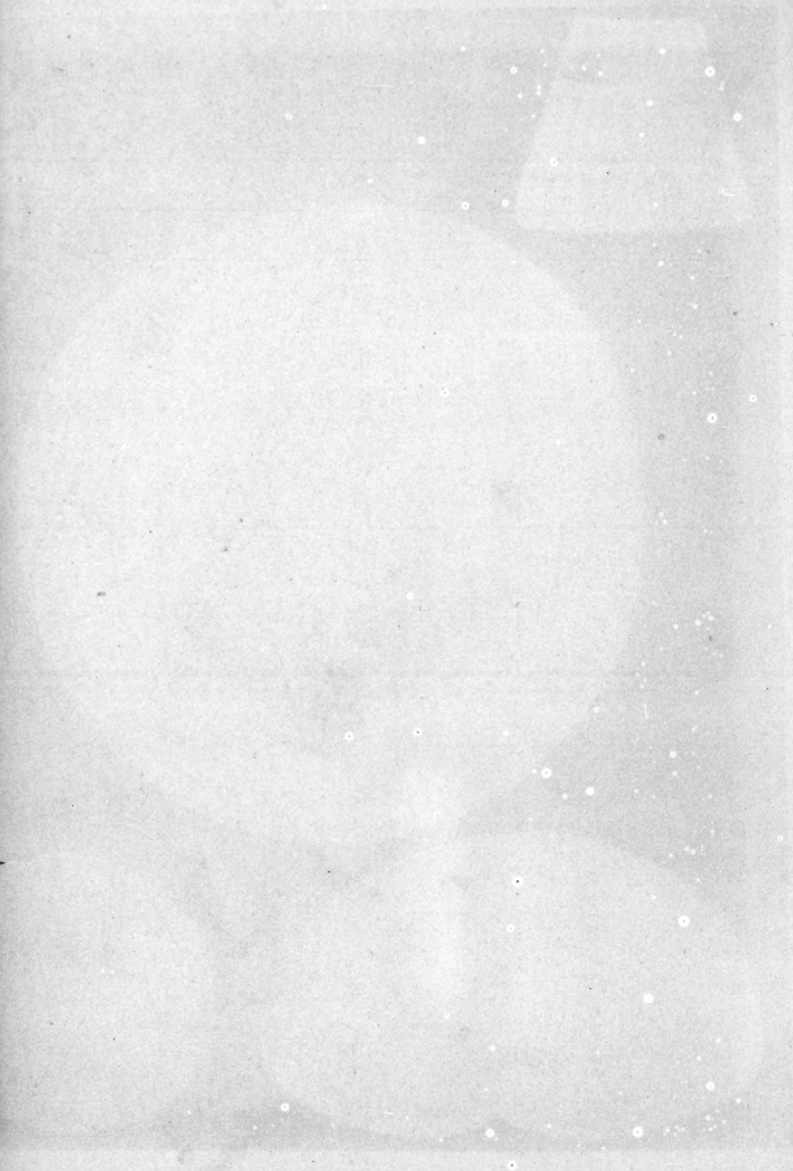
1 TO 10 FROM PHOTOGRAPHS. 11 TO 14 FROM PHOTOGRAPHS & DRAWINGS.

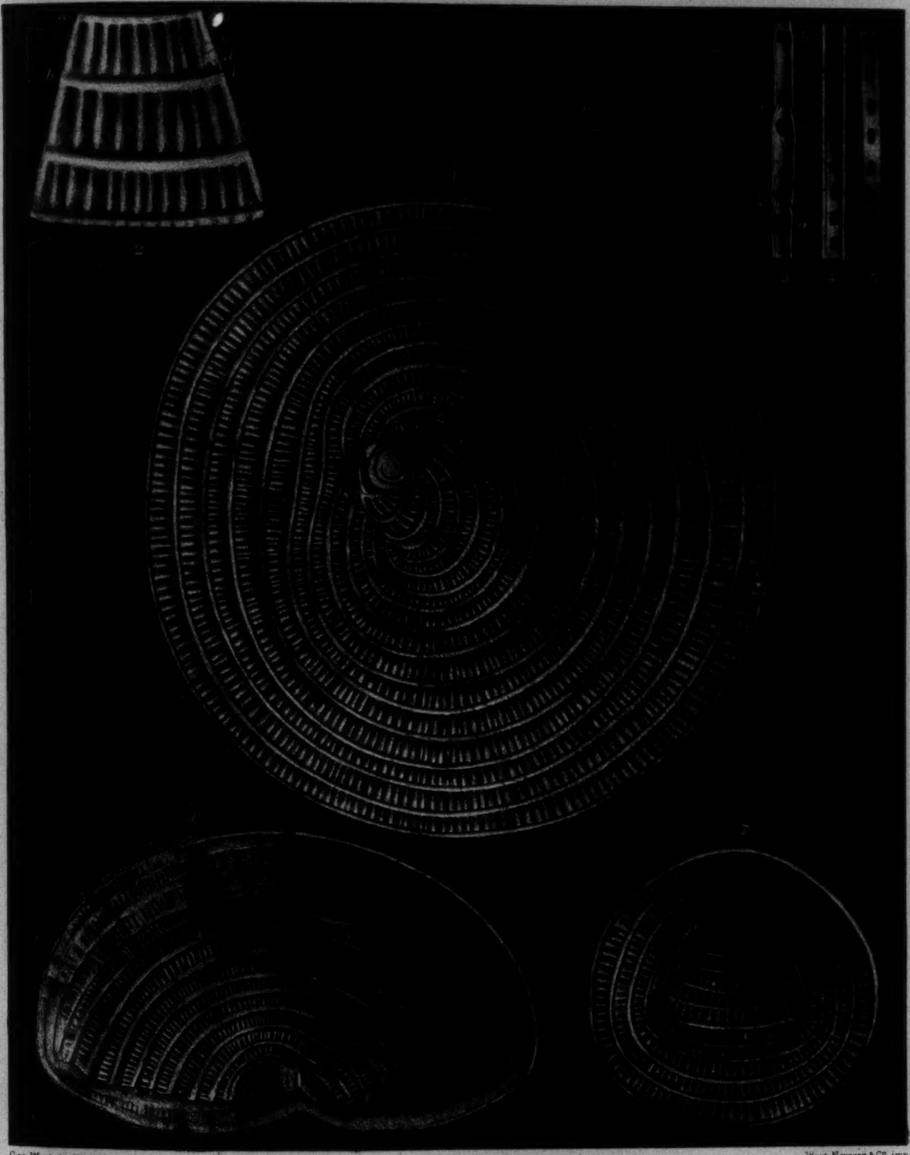




D.J. Pound Sculp.

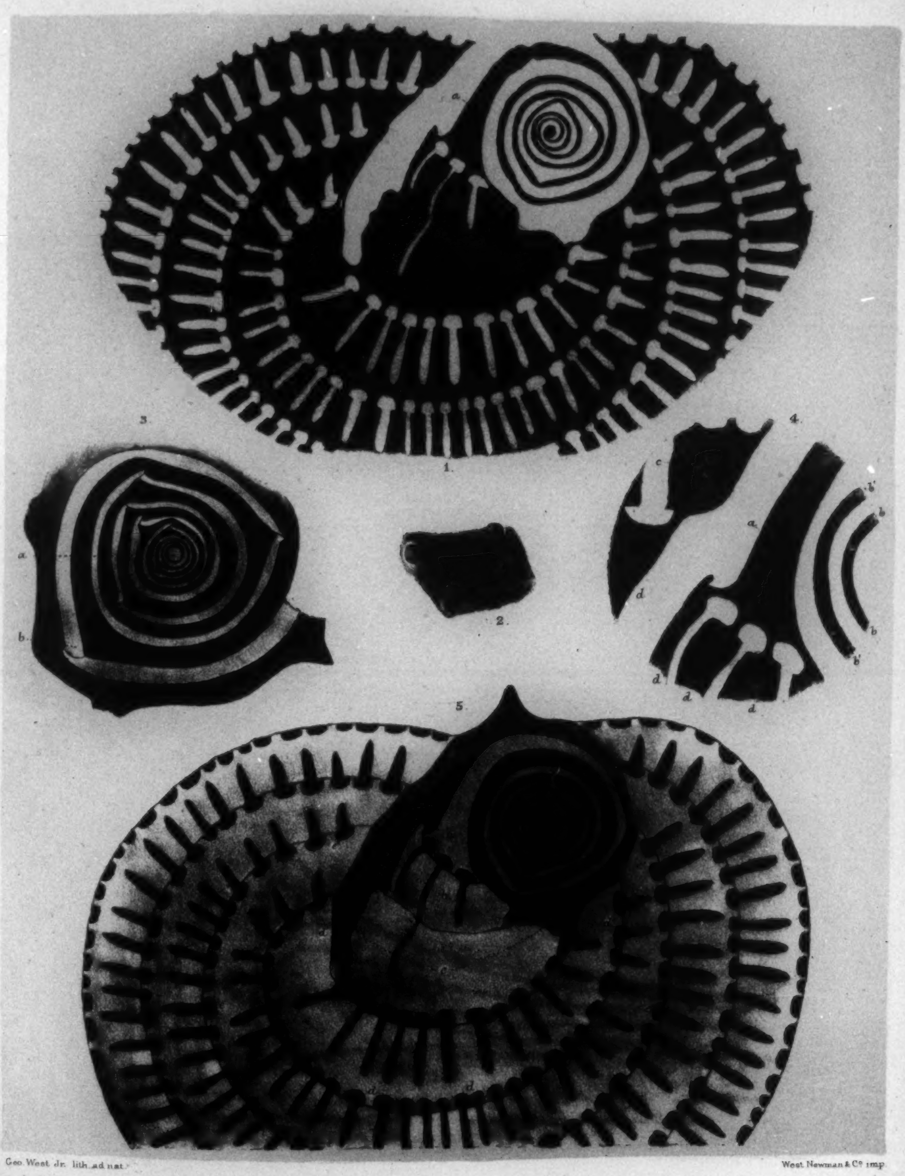
FROM PHOTOGRAPHS.





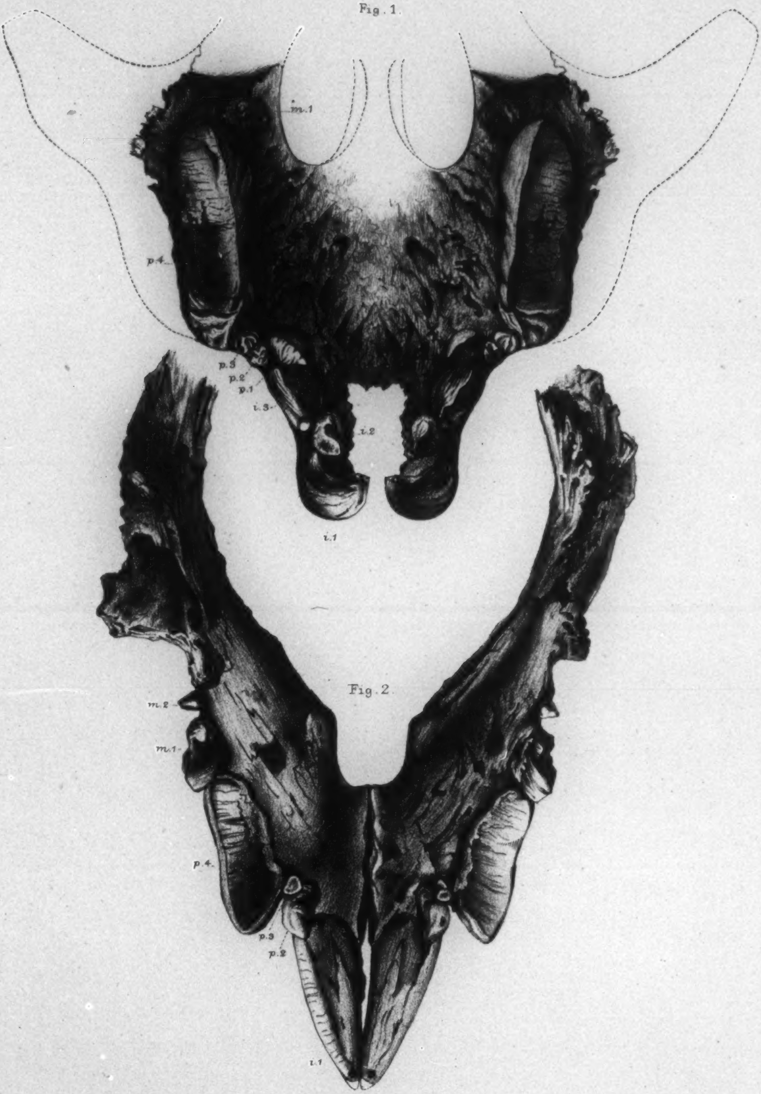
Geo. West Jr. lith ad nat.
West, Newman & Co. imp.

ORBITOLITES TENUISSIMA.



Geo. West Jr. lith. ad nat.
West, Newman & Co imp.

ORBITOLITES TENUISSIMA.



THYLOCOLEO CARNIFEX

West, Newman & Co. lith.

Fig. 1.

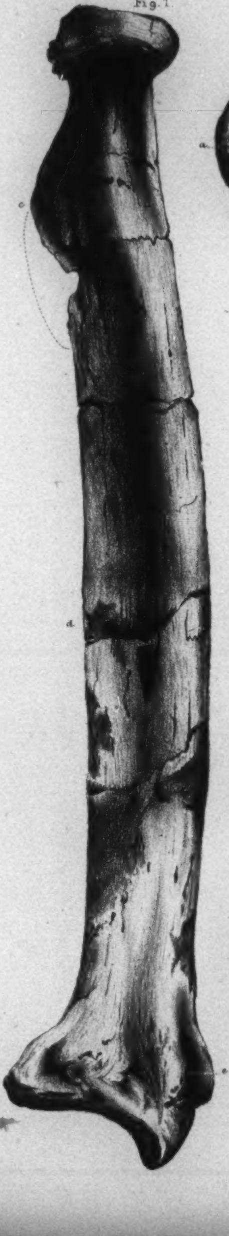


Fig. 2

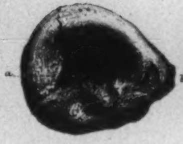


Fig. 3.

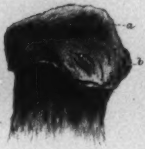


Fig. 4

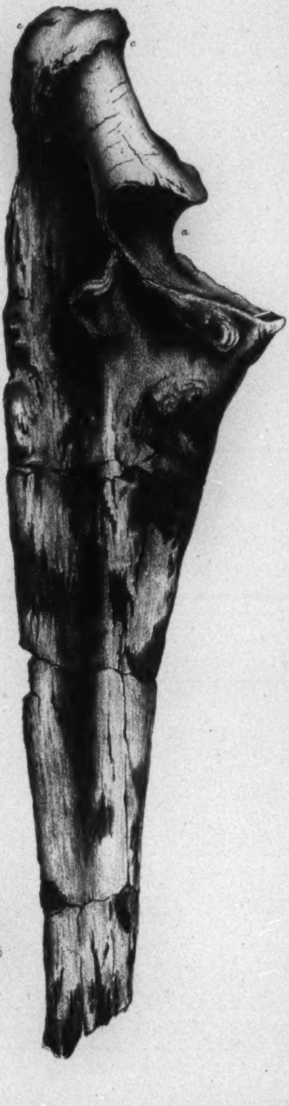


Fig. 5.

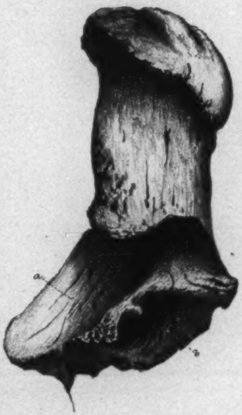


Fig. 6.

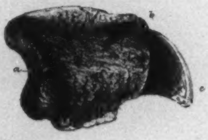


Fig. 7.

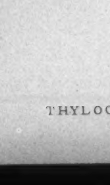
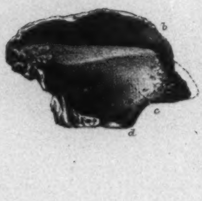


Fig. 8.



THYLOCOLEO CARNIFEX.

West, Newman & Co. lith.

Fig. 5

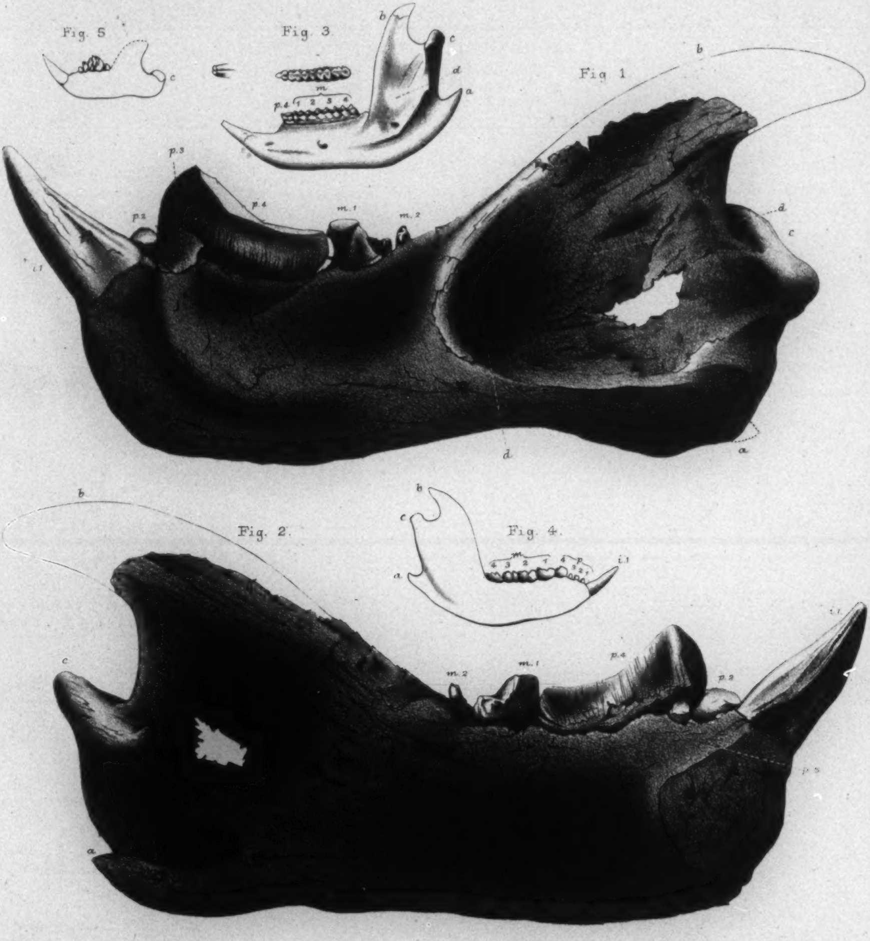


Fig. 3

Fig. 1

Fig. 2.

Fig. 4.

West Newman & Co. lith.

THYLOCOLEO CARNIFEX

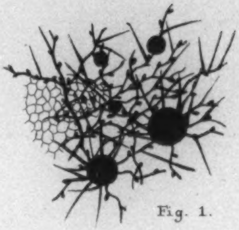
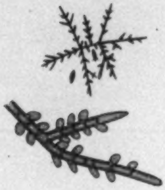


Fig. 1.

Fig. 2.



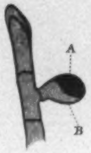


Fig. 9.

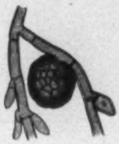


Fig. 26.

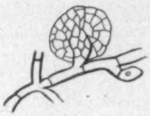


Fig. 27.

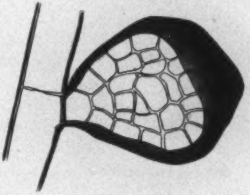


Fig. 31.

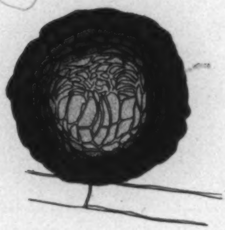


Fig. 34.

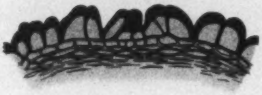


Fig. 35.

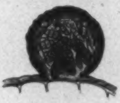


Fig. 36.

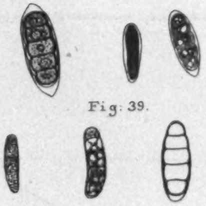


Fig: 39.

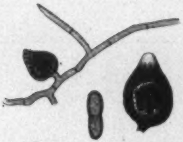


Fig. 41.

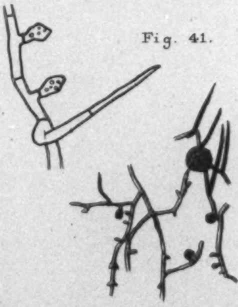
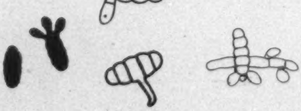


Fig. 40.



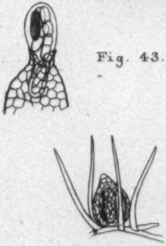


Fig. 43.

West Newman & Cº chr. lith.

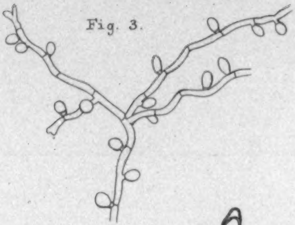


Fig. 3.

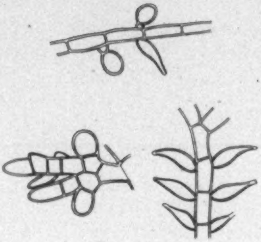


Fig. 4.

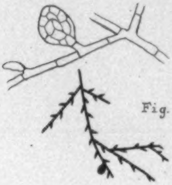


Fig. 5.

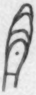


Fig. 7.

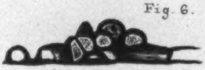


Fig. 6.

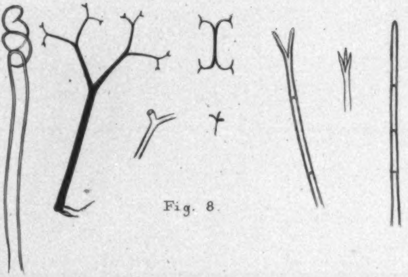


Fig. 8.

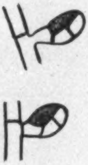


Fig. 10.

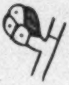


Fig. 11.

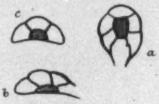


Fig. 12.

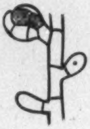


Fig. 13.

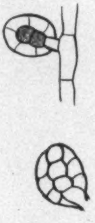


Fig. 14.

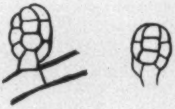


Fig. 15.

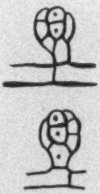


Fig. 16.

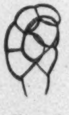


Fig. 17.

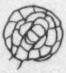


Fig. 18.

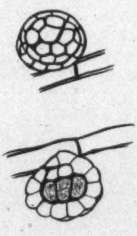


Fig. 19.

West, Newman & Cº lith.

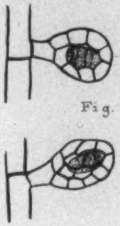


Fig. 20

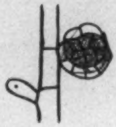


Fig. 21.

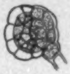


Fig. 22.

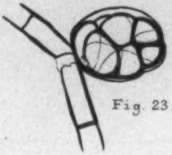


Fig. 23.

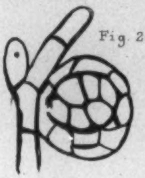


Fig. 24.

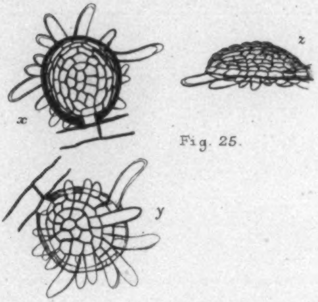


Fig. 25.

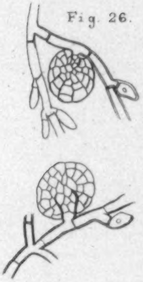


Fig. 26.

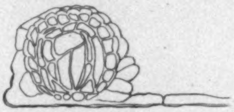


Fig. 28.

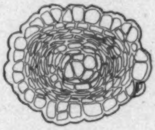


Fig. 29.

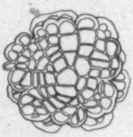


Fig. 30.

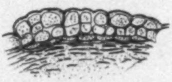


Fig. 32.

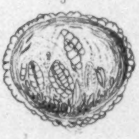
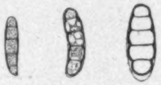


Fig. 33.



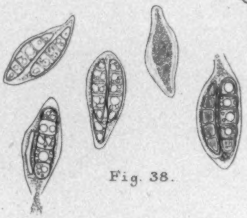


Fig. 38.

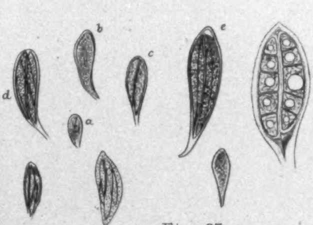


Fig. 37.

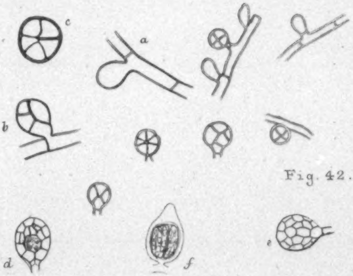
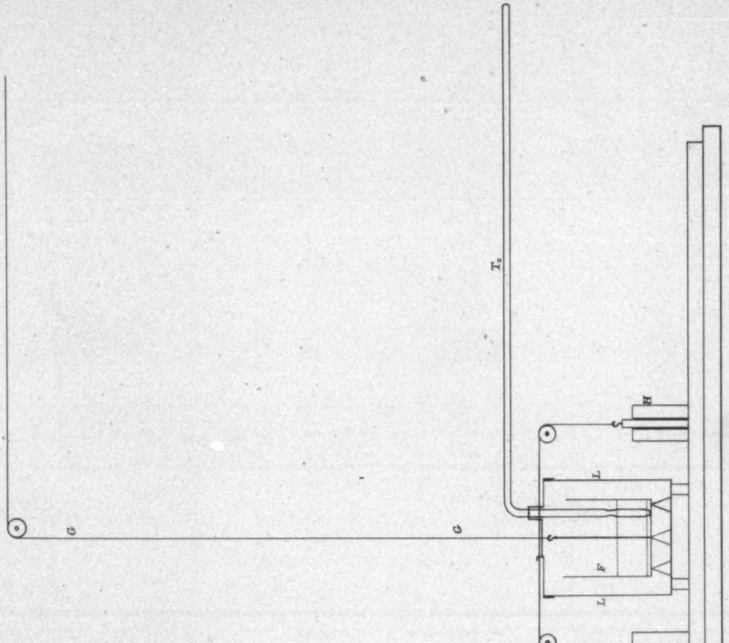


Fig. 42.

West Newman & Cº lith.



Atomic weight of Glucinum:

Calorimeter for determining specific heat of the metal.

(Scale: 5 m/m = 1 c/m.)

West, Newman & Co. lith.

Fig. 1.

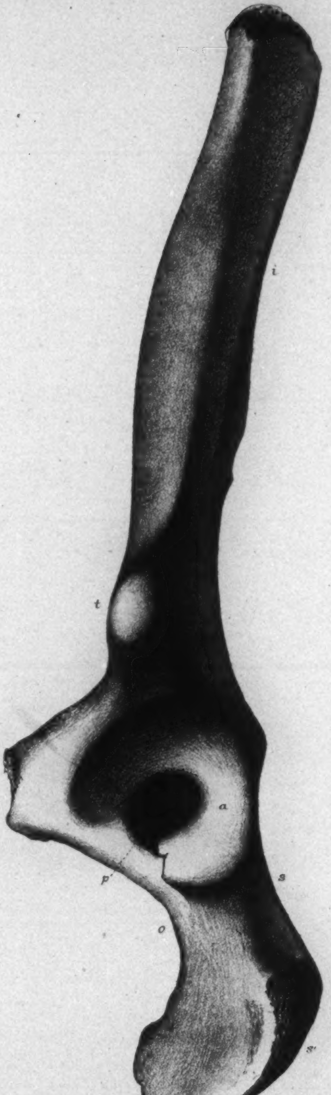


Fig. 2.

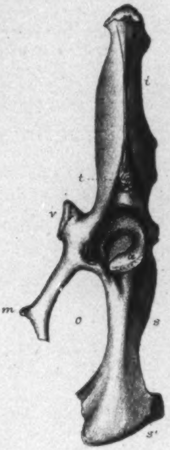


Fig. 4.

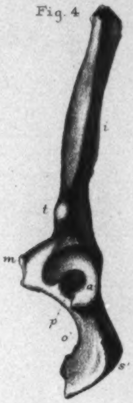


Fig. 3.

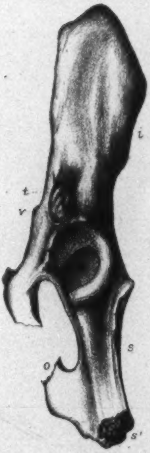
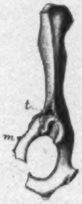


Fig. 5.



West, Newman & Co. imp.

Reinold & Rücker.

Phil. Trans. 1883. *Plate* 47.

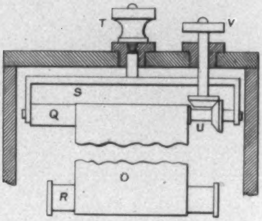


Fig. 2.

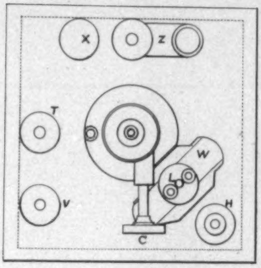
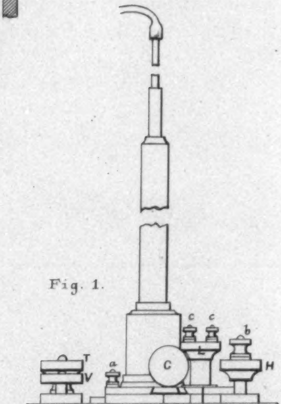


Fig. 3.

Fig. 1.



West Newman & Co. lith.

Fig. 2.

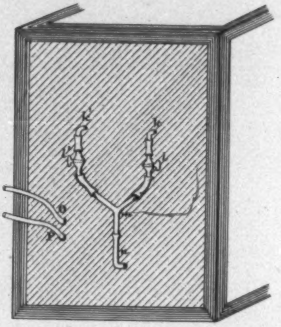


Fig. 3.

Fig. 4.

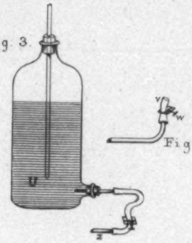
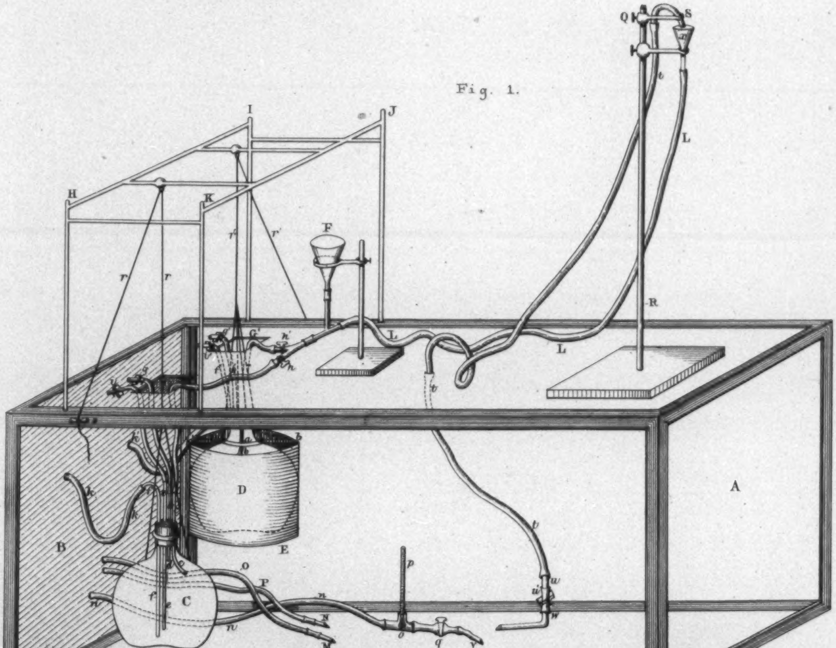
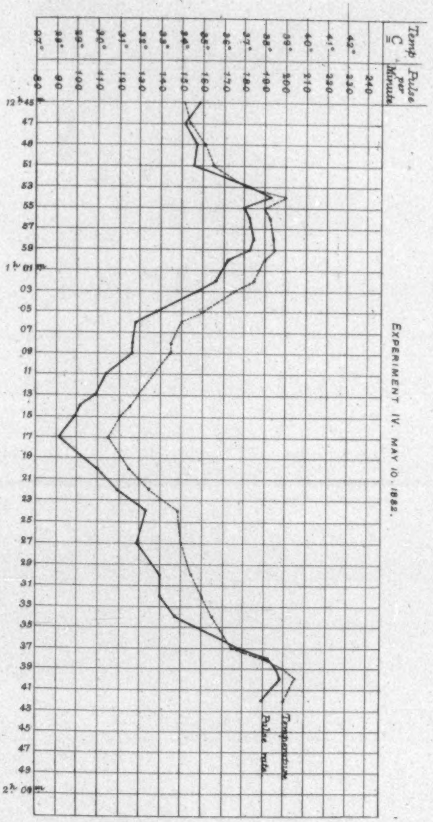
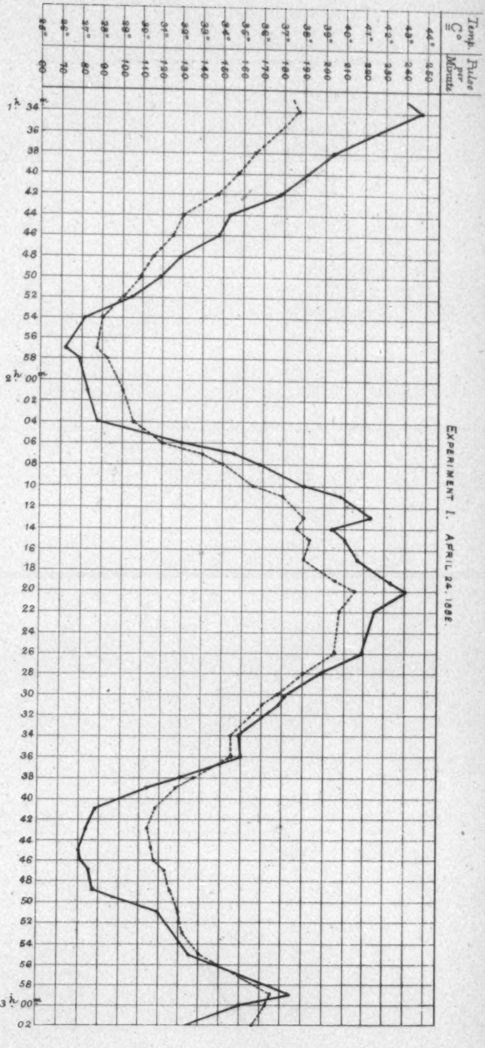


Fig. 1.



West Newman & Co. lith.


EXPERIMENT IV. MAY 10. 1882.


EXPERIMENT I. APRIL 24. 1882.

West Newman & Co lith